BIOGAS
Energy From Animal Waste

Written for the Solar Energy Research Institute

by

David G. Palmer
Energy Systems Consultant
Paradise Hill Drive
Union Springs, NY 13160

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Project Leader, SERI

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Introduction

It is no secret that escalating costs of energy are a growing menace to farm profit and loss statements. Substantial savings can result, though, from facing these costs head on—by applying conservation measures and taking full advantage of farm energy resources, including manure. The organic matter in manure is a form of stored solar energy, which can be unleashed as gas to help meet farm energy needs. In many cases, biogas can play a role in improving profitability and helping to achieve relative energy independence for the farm.

This book is for livestock and poultry farmers, students, county agents, energy advisors, and others interested in biogas. It is designed for people with a basic knowledge of farm operations. The purpose is to provide an understanding of how biogas can be produced and used, and to set a frame of reference for assessing the operations that make sense for biogas production. This material is not intended as a system design or operations guide, however. Professional help is advised for planning and designing individual applications. Sources of assistance and more advanced and detailed information begin on page 25.

Biogas Defined

Biogas is a mixture of methane, carbon dioxide, water vapor, and traces of other gases produced by bacteria when organic materials decay in the absence of oxygen. The process is called *anaerobic* digestion, in contrast to *aerobic* digestion which means decay in the presence of oxygen (as in a compost pile). Anaerobic digestion occurs in two stages. In the first stage, a fast-growing group of bacteria, called acid formers, breaks down organic matter into a variety of organic acids. In the second stage, a slower growing group of bacteria, called methane formers, converts these organic acids to methane and carbon dioxide.

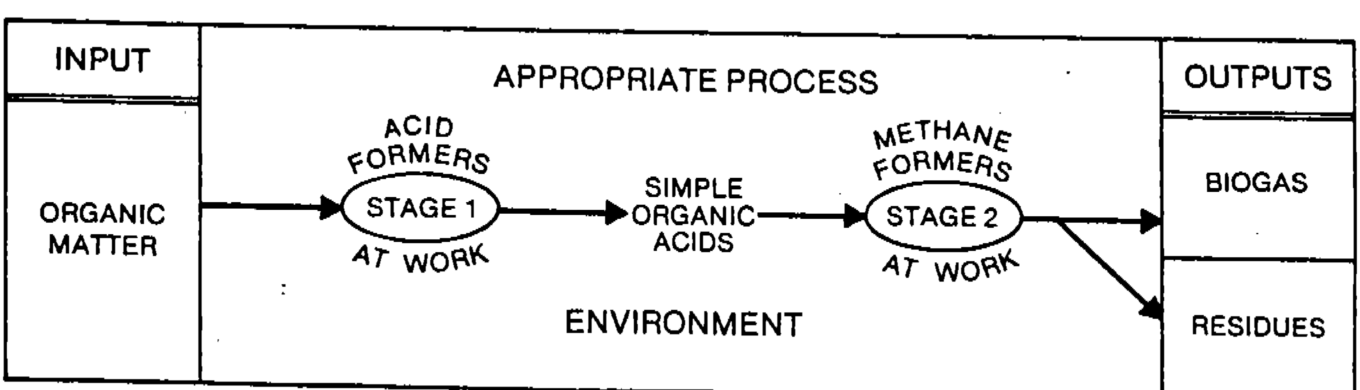
Methane, the principal component of natural gas, contains about 1,000 Btu/ft^3 under standard conditions. (A Btu is the amount of heat energy necessary to raise the temperature of one pound of water one degree Fahrenheit, or it can be thought of as roughly the amount of energy yielded by burning one kitchen match.) Biogas is approximately 60% methane and can be used as a substitute for natural gas. However, because only the methane portion will burn, biogas contains about 600 Btu/ft^3.

1000 ft^3 of biogas	=	600 ft^3 of natural gas
	=	6.6 gal of propane
	=	5.9 gal of butane
	=	4.7 gal of gasoline
	=	4.3 gal of #2 fuel oil
	=	44 lb of bituminous coal
	=	100 lb of medium-dry wood

Fuel Equivalents of Biogas

Manure as a Biogas Feedstock

Although under the right conditions almost any organic material can be anaerobically digested to produce biogas, the focus here is on animal manure. Food is only partially digested in an animal's digestive tract. The remaining food becomes manure, which still has plenty of organic fats, proteins, carbohydrates, and other nutrients to feed gas-producing bacteria. If manure is routinely left on the floor or ground,



Anaerobic Digestion Simplified

aerobic bacteria decay it, producing a small amount of heat and ammonia, but no biogas. Controlled anaerobic digestion simulates digestive system conditions of air-free surroundings and a warm temperature but increases the time period in which digestion occurs. In an artificial environment, bacteria can work on the remaining organic particles in manure long enough to achieve more complete digestion and biogas production.

The Digester Introduced

This artificial environment can be provided in a closed, heated container called an *anaerobic digester*. An anaerobic digester may also go by the name *methane fermentor* or *reactor*, and some prefer *biogas generator* or *biogasifier*, but simply *digester* will suffice here. Almost any type or shape of container will work, but practicality has typically led to use of cylindrical tanks. A slurry of manure and water is fed into the tank where it digests over a period of days or weeks before being discharged. Biogas is formed as organic matter in the slurry decomposes. The gas bubbles up through the liquid and either accumulates in the space above the surface or is transferred to a separate storage container. Equipment or appliances then draw off the gas as needed. Usually these are set up to switch to a backup fuel during periods when production and storage are inadequate to meet demand.

Farm Digester Development in the United States

Efforts to produce and use biogas are quite recent on the American agricultural scene, but the idea has become very popular in other parts of the world. During World War II, farmers in Germany and other European countries turned to digestion when fuel supplies were scarce. In developing countries, fuel scarcities and high costs have led to widespread use of digestion to produce cooking fuel. In India, for example, experiments to design a simple, low-cost, cow-dung digester began in 1939 following the successful demonstration of residential use of biogas, piped from the Bombay Sewage Treatment Works. About 50,000 digesters have since been built in India, and recent reports from China state that over seven million rural digesters have been built there since 1970.

For many years, sewage treatment plants in this country have used anaerobic digestion to stabilize biological activity in human wastes. In most plants, however, the production of biogas has been considered incidental. The extra effort necessary to capture and use the gas has not traditionally been justified in view of the ready availability of other low-cost fuels.

In the wake of energy shortages, price increases, and pollution control requirements, researchers and environmental advocates have led the way in developing practical biogas systems in this country. Agricultural engineers at Cornell University, for example, have developed a prototype owner-built digester for small farms. The focus at Cornell has been on simplified operation and the use of low-cost materials and construction techniques. In the State of Washington, the State Department of Ecology funded a digester installation on a 200-head state dairy farm as part of a program to upgrade the farm's manure handling system for water pollution control. The biogas is used in a boiler to process milk in the farm's creamery. Digesters are also becoming increasingly popular on various types and sizes of private farms. Units now in operation are successfully producing biogas from swine, poultry, dairy, and beef cattle manure.

Components of a Farm Biogas System

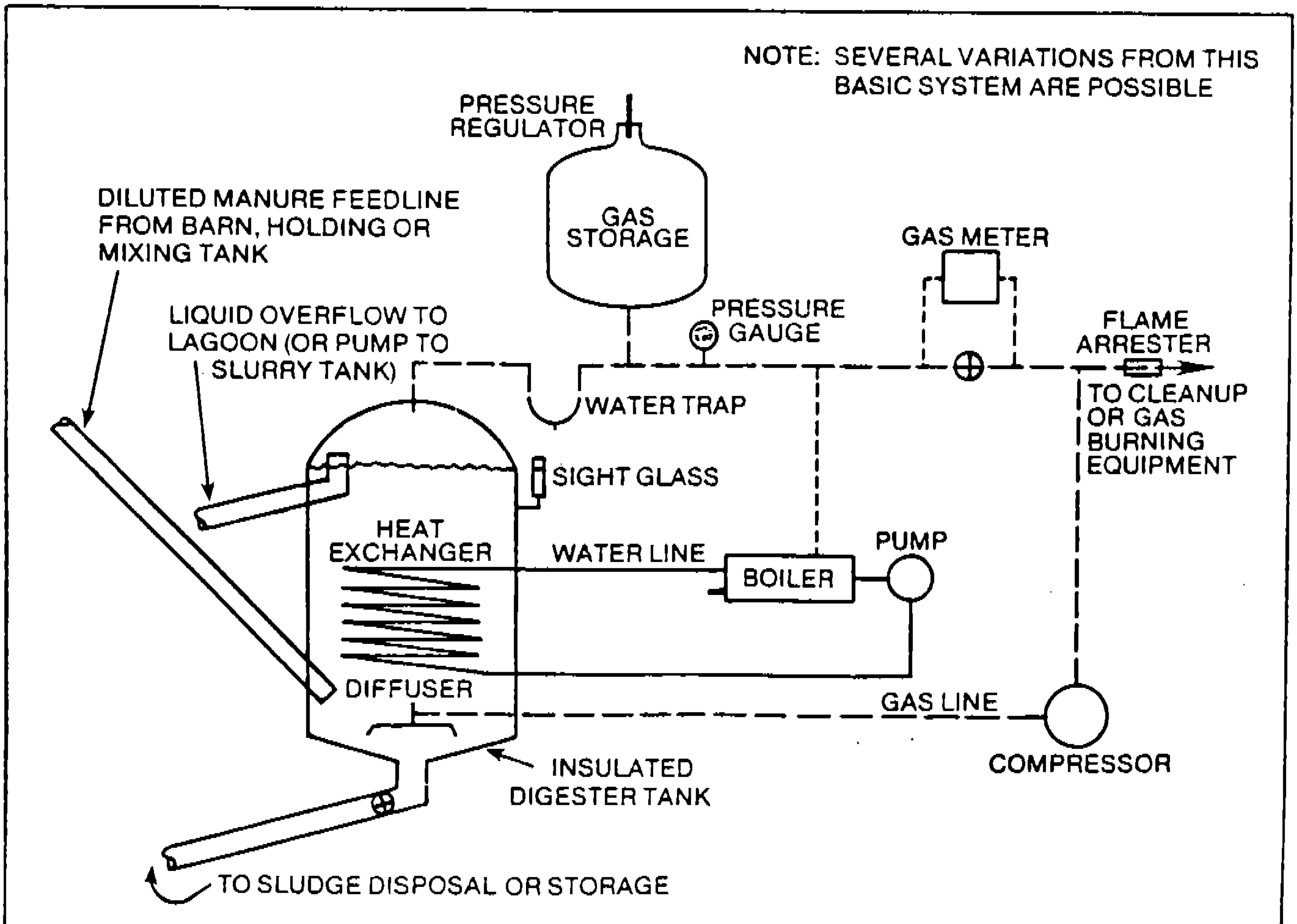
Since every livestock operation has a unique set of problems and requirements, each biogas system must be custom tailored to the particular situation. There are, however, basic components and operating principles which all systems share. Not counting buildings, controls, gas burning equipment, or effluent storage or disposal, the three main components of any farm biogas system include:

- A manure handling system;
- A digester, with provisions for mixing and heating; and
- A gas handling and storage system.

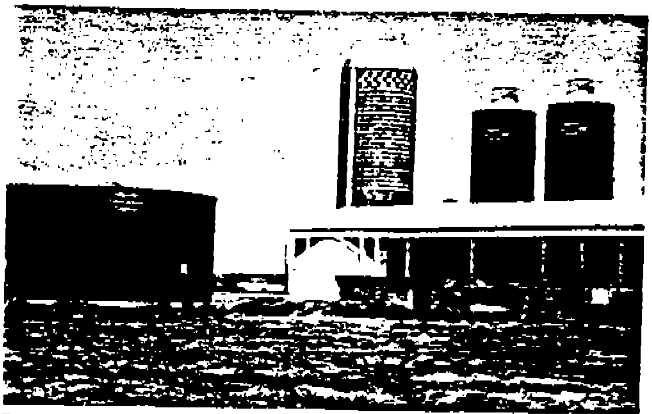
Manure Handling—A Priority Concern

Successful digester operation is impossible without efficient and appropriate manure handling, so the cost, design, and overall benefits to be derived from anaerobic digestion will depend somewhat on the equipment already in place. Indeed, a digester can be viewed merely as an optional component in a waste management system. For some farmers, investment in biogas production will also require an improved system for manure collection and storage—and perhaps a rethinking of disposal or fertilizing practices. With good planning, a traditional waste disposal headache can become an important farm asset.

Freshly voided manure immediately begins decomposing, diminishing in biogas-producing potential with age. It therefore should be collected and fed to the digester as soon as possible. If it can actually be fed warm, an additional benefit results from a reduced digester heating requirement, but this is seldom practical since the risk of explosion precludes locating the digester inside a confinement building. Manure must be flushed,



Simplified Schematic of a Farm Biogas System



Example of a tidy small-scale waste management system including a digester. Photo: Iowa State University

NOTE: Sixty head beef cattle open confinement barn (with slotted floors) at right.
Insulated white digester at center. Overframe is for mechanical mixer drive unit.
Partially underground pumphouse to right of digester.
Manure holding tank consisting of two concrete culvert sections to right of pumphouse.
Six month effluent storage tank at left.

pumped, scraped, or hauled from the building either to a holding facility or directly to the digester.

The fraction of water in the slurry can be critical. Too little water makes pumping difficult; too much requires an unnecessarily large digester capacity. Good pumpability and gas production are generally obtained when dry matter is restricted to the 8%-13% range (about the consistency of cream to thick pancake batter) depending in part upon manure type. Manure moved mechanically in more solid form must be diluted accordingly before digestion. Drier manures, such as poultry or that mixed with bedding and foreign materials, may also require mixing prior to digestion. A predigestion mixing or settling tank may or may not be called for, depending upon the situation and the system being installed.

Depending upon climate and overall system design, it may be worthwhile to use warm effluent to preheat the influent, thus reducing the amount of energy required to maintain proper temperature of the digester contents. There are a number of ways this can be done, but probably the simplest is a method under study at the University of Missouri at Columbia. With this method, the heat exchange occurs by direct mixing of the influent and effluent. Operation is as follows: One hour before the digester is to be loaded, effluent equal in amount to the influent is drained from the digester into a collection basin, where it is mixed with the influent, thus exchanging heat. Influent solids settle toward the bottom, along with some undigested solids from the effluent. The upper half of the slurry is then pumped into an effluent storage container, and the lower half is pumped into the digester. This method has been dubbed the "backflow heat exchanger," after the flow pattern of effluent from the digester back to the collection basin. This approach to preheating appears to be well suited to hog operations that use a lot of water to flush manure, making it very dilute as it leaves the barn.

An alternate method of heat recovery is to pump influent through a heat exchanger (which does not allow mixing) located inside an effluent holding tank. However, an effluent holding tank is not always required, and it is unlikely one would be justified solely for the purpose of slurry preheating. There are no good guidelines for determining how much extra investment is advisable for preheating; it depends largely upon the characterisics and location of the individual system.

The Digester

Types of Digesters

There are various ways of categorizing digesters. The loading pattern provides one means of differentiation. Batch-loaded systems are restarted with each new load, which is digested over a multiple-week or multiple-month cycle and is then unloaded. These are impractical for most farm situations except where manure can be conveniently moved and stored in relatively dry form. Continuous loading applies to either literally continuous or periodic loading and discharging. Daily cycles are most common, but weekly loading and discharging works satisfactorily and may be more convenient for some systems. Discussion here is limited to continuously loaded digesters because of their more common use.

Digesters have been built in various shapes, traditionally with rigid walls of poured or block concrete, steel, or fiberglass. For example, vertical axis, cylindrical shapes (such as silos) are popular rigid-wall containers. This shape allows good, even mixing during digestion; has a good volume to surface ratio; is strong and simple to build; and is relatively easy to increase in capacity by adding top sections. A number of package systems are now available, with digesters ranging from rigid steel tanks to flexible plastic bags. These systems can be obtained complete with heat exchanger and hot water circulation pump, insulation, and all necessary accessories.

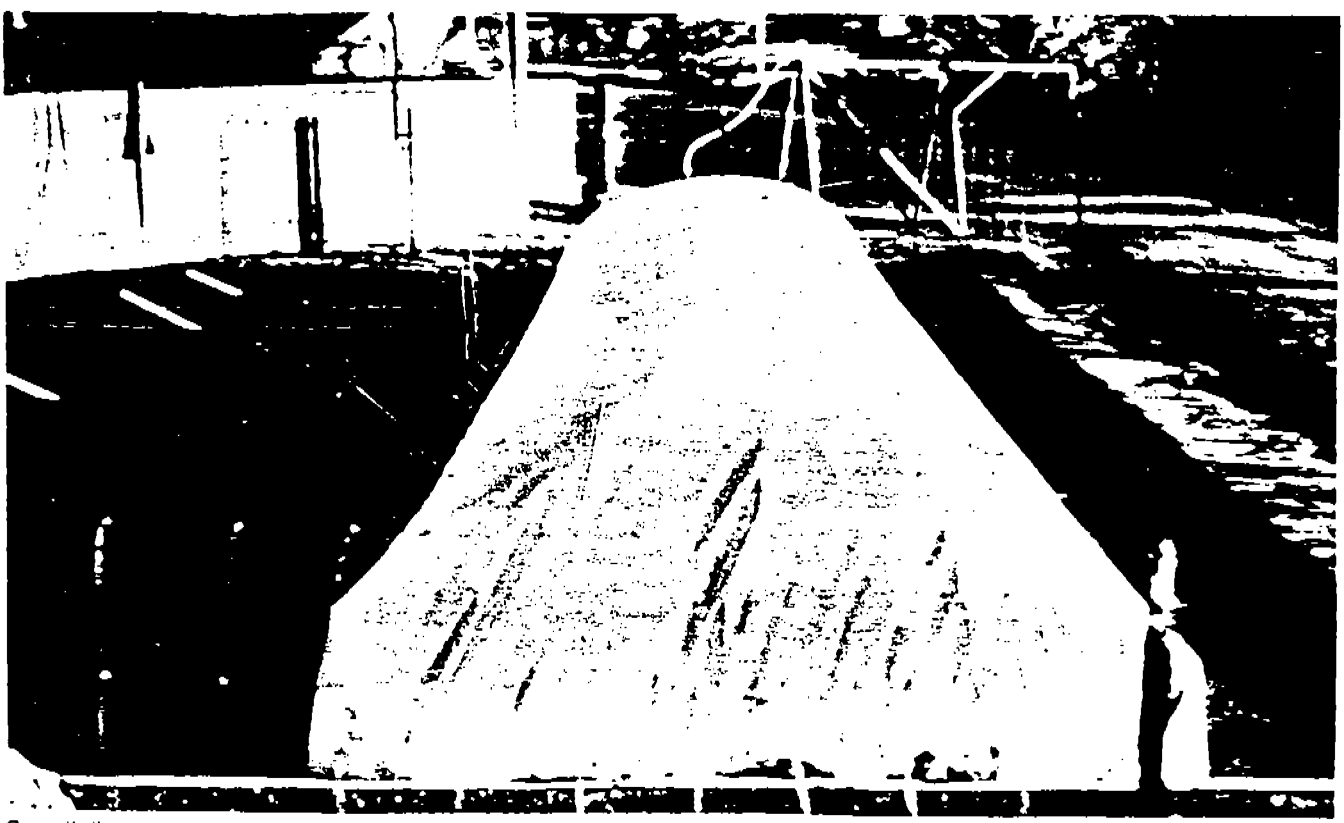
The amount of mixing necessary will vary from system to system and is dependent upon digester design, manure type, and presence of straw and other debris. Some digesters operate successfully without any mixing. However, scum accumulation on the slurry surface may require periodic removal. Mixing reduces settling, helps assure intimate contact between bacteria and manure, and helps to maintain uniform temperatures. Intermittent mixing is generally adequate and can be accomplished by mechanical stirrers, by liquid recirculation, or by recycling some of the biogas through diffusers at the tank bottom. With proper design, some mixing also occurs during loading. Manure can enter near the digester bottom, helping to resuspend settled solids, or at the top, providing some mixing action in the slurry. Effluent equal in volume to the influent is either forced out as overflow during filling or drained or pumped out prior to filling. This is stored in a tank or lagoon pending use or disposal.

A departure from traditional rigid wall tank digesters is found in a design developed at Cornell University. The digester pictured was first placed in operation in March 1978. It is an insulated, soil-supported structure, lined and covered with a gas-tight rubber membrane for biogas collection. Manure is fed daily into one end of the digester and flows by gravity for a period of about 20 days to the opposite end, where a discharge port daily passes effluent equal in amount to the influent. This type of digester is known as "plug flow," after the way each daily charge of manure moves along from one end of the long, narrow digestion chamber to the other end during its retention cycle. The rubber cover, just slightly larger in volume than the digester itself, provides storage for about two hours of gas production. Longer term storage requires use of a separate container. Alternatively, a flexible cover, which expands and contracts as gas production exceeds or falls below the usage rate, has been used elsewhere with this design to provide up to about one-half-day's gas storage. The Cornell system was designed for a 50- to 65-cow dairy, but it can be scaled up for larger operations.

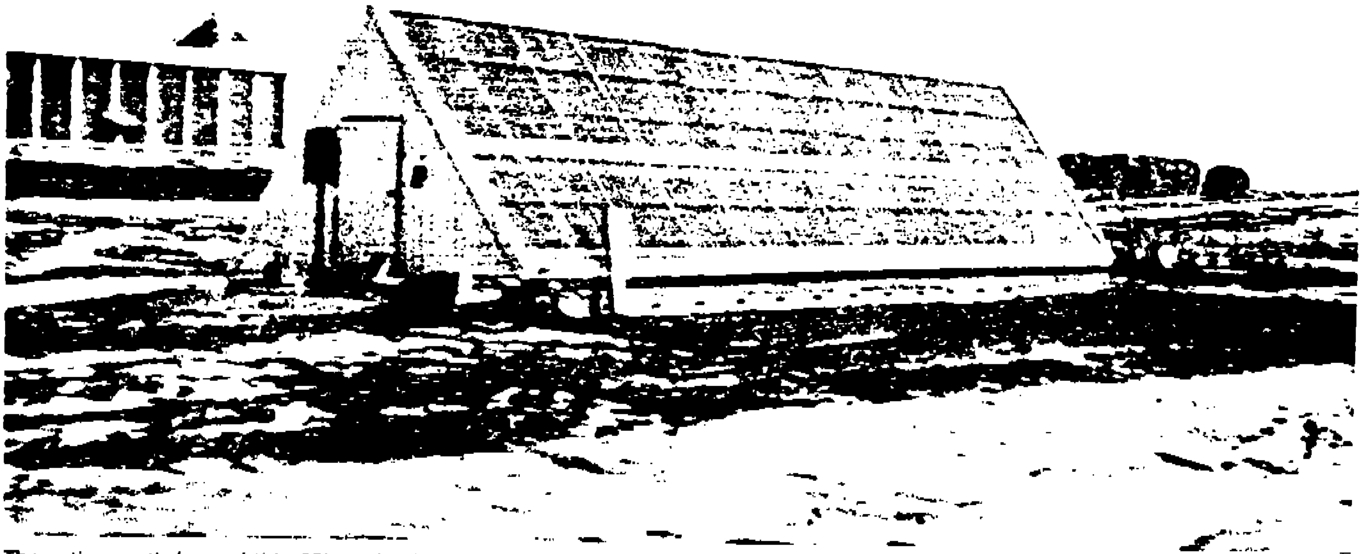
Plug flow digesters are usually horizontal, and although they can be constructed with rigid walls, the major motive for their development and use is their ability to use inexpensive excavated trenches for support. One advantage of this design is that no mixing is required for digestion of dairy manure. This design has not been tested, however, with other manure types. Intermittent mixing for short periods would most likely be required for processing less homogeneous swine or poultry manures.

Innovative developers have demonstrated various ways of custom-building digesters from low-cost materials. Plastic bags can be fabricated in any shape and size, and even fitted with baffles to provide plug flow retention. Properly sized, the bags double as gas collection and short term storage chambers, and additional bags can be connected for auxiliary storage. The digester bags can be supported by sod in excavated trenches, or by concrete, steel, or simple wood frames above ground. Insulation of above-ground bags is simplified by the design of the support structure. The bag-type system is simple and inexpensive to build, offering advantages particularly to farmers with a relatively small number of animals.

Digester heat is most commonly provided by using some of the biogas produced to fire a boiler, from which hot water is circulated under thermostatic control through pipes inside the digester. External heat exchangers also have been used, but internal units make more sense in most cases,



Cornell digester



The entire south face of this 60' x 14' A-frame is a solar collector from which warmed water is pumped through a heat exchanger in a 46,000 gal. insulated plug flow digester located beneath the A-frame, which also serves as an equipment building. The system was placed in operation in 1980 on the Raymond L. Cerise hog farm in Kellog, Minn. The solar collectors provide year-round 100% of the process heat necessary to maintain digester contents at 95°F. Digester effluent overflows into a lagoon, snow-covered in the foreground. A 1300 head hog finishing building behind the A-frame also is solar heated. Scrubbed biogas is now used for home heating but is intended for corn drying upon completion of a 20,000 bushel grain bin.

since it is easier to pump pure water than manure slurry, which also tends to be corrosive. Convection currents from internal heat pipes are also credited with providing a mixing action. This is especially important with Cornell-type plug flow digesters that do not have mixing devices.

A solar collector system should be investigated as a supplement to a boiler or water heater. Depending upon farm location, tax credits, and other factors, the added investment for solar heating may be justified by savings in biogas consumption. Collector arrays which work well with digester heating systems can be purchased ready-made or can be hand-fabricated from available plans. Consultation with someone experienced in sizing and costing solar heaters is recommended.

In cases where biogas is used primarily to fuel an engine, e.g., for generating electricity, the recommended practice is to circulate water between the digester heat exchanger and the engine's radiator. This ordinarily provides more than enough heat to maintain the required digester temperature. Engine heat can also be recovered by using exhaust heat exchangers, providing space heating, grain drying, or even steam heating for an alcohol still.

New digester designs under study may offer advantages over conventional systems for some farm applications. The main emphasis is on finding improved ways of accommodating slurries either much drier or much more dilute than those conventionally used. Manure from poultry or from stalls with bedding could be more conveniently handled and digested, for example, if the process could be carried on with a higher fraction of dry matter. Under development at Cornell and other locations are new "dry process" digesters which will be batch loaded with manure and various other organic material only a few times per year.

Farmers planning digesters may wonder about the effect of mixing other biodegradable materials and residues with manure. With proper management, materials such as low-quality hay, old straw, and even leaves and grass clippings can produce biogas themselves, and research at the University of Missouri at Columbia has shown that the right combination of additives can actually increase the amount of gas recovered from each pound of manure solids. Most conventional manure digesters can handle a certain amount of extra cellulosic material, but a modified design should be considered by anyone with an interest in producing gas from high concentrations of relatively dry, infrequently collected organic materials.

Some small farms may be suited to a relatively new method of digesting very dilute slurries. An *anaerobic filter* digester uses a container of fine stones to process dilute slurries at high flow rates. Bacteria are first grown on the surface of the stones. The bacteria tend to remain attached to the stones as the liquid passes through the filter, increasing the bacterial population immediately available to decompose manure solids and thereby speeding the treatment rate. One advantage of the process is that less heating is necessary. Digester temperatures 20°-30°F lower than customary provide satisfactory results, according to experiments with swine manure at the National

Hypalon floating cover acts as a gas collector over this anaerobic lagoon. Farmers' Cooperative Elevator Co., Radcliff, IA.

University of Ireland at Galway. These experiments have yielded biogas with 80% methane content from an inexpensive upflow anaerobic filter digester. The Irish researchers allow a mixture of about 2% solids to settle in a tank for five days. The very dilute upper third is then drawn off and forced up through the filter, spending just two days in residence, and providing extremely fast production of methane-rich gas. Digester effluent overflows as fresh influent is admitted to the filter bottom, and the settled mixture in the lower two-thirds of the tank is pumped off with the effluent and used as fertilizer. Although the Irish experience with the upflow filter digester has been very favorable in terms of reduced capital cost and operational simplicity, insufficient experience with this new system precludes detailed discussion or recommendations on its use at this time.

Although not built primarily for the purpose of biogas production, an anaerobic lagoon can be considered another type of digester. Some farmers with anaerobic lagoons may find it practical to recover biogas by simply covering all or part of their lagoons. Lagoons contain a low percentage of solids and ordinarily function at too low a temperature to be considered efficient digesters, but they do produce gas. A number of things can be done to stimulate biogas production, including periodic agitation, heating, and insulating, but the costs and benefits of devising a gas recovery system for a lagoon depend entirely upon the individual situation.

A farmer should be very careful in selecting a digester type. Not only should the expected costs of operation and maintenance be reviewed along with installation cost, but the requirements for monitoring and tinkering should be considered for compatibility with the farmer's management style and personal preferences.

Sizing the Digester

The digester is the most expensive component of the conventional, non-power-producing biogas system. Because size is a primary determinant of digester cost, sizing is important to a farmer considering investment in a biogas facility. Excessive digester capacity translates to inefficient operation. Four related factors must be considered in determining minimum capacity: *retention time, temperature, influent solids concentration,* and *loading rate.*

Retention time refers to the length of the digestion cycle, or the average number of days each particle of organic matter is retained in the digester, undergoing conversion to biogas. It also can be thought of as the number of days of manure slurry production that must fit into the digester. Hence, if retention time is increased or decreased, the required digester size increases or decreases proportionately.

The temperature at which digester contents are maintained has an inverse relationship to retention time; required digester size decreases as operating temperature increases. Biogas can be produced at temperatures ranging from 60°F to about 140°F. Between these extremes there are two optimal temperature ranges named after the bacteria that thrive at these temperatures. *Mesophilic* methane formers function up to about 115°F, achieving their highest rate of biogas production at about 95°F. *Thermophilic* bacteria function in the upper range, with efficiency peaking at about 130°F. Because biogas is produced faster at thermophilic temperatures, many experimental digesters have been designed to operate in this range. The higher temperature requires more heat input and, because thermophiles are very sensitive to changes in their environment, more managerial attention. Consequently, mesophilic digestion is recommended for most farm situations. Indeed, about 95°F has become commonly viewed as standard both in sewage treatment and for biogas production. However, 95°F is not necessarily best in every case. Thermophilic digestion may be preferable for some large installations, and less than 95°F may make economic sense in cases where digester size is not critical.

For example, given enough time, an ambient temperature digester of about 80°F should produce as much biogas as it would at 95°F. A longer retention time would be required at the lower temperature, though, so a larger digester would be needed to accommodate the extra days' manure production. In some cases, the extra cost for an increased tank size may be less than the cost of equipment and gas saved by not using a heat exchanger. Such cases are probably limited to southern climates, however.

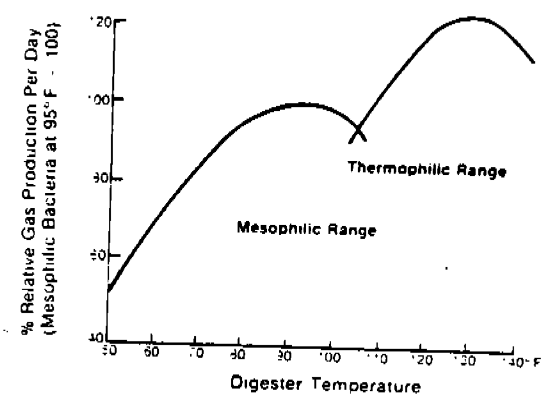
Farmers following the conventional wisdom of fitting their digesters with heat exchangers should ordinarily also plan for the standard operating temperature. To the extent that excess capacity is available, experiments can then be conducted if desired to test the results of operating at lower temperatures. At 95°F up to four weeks retention may be necessary for relatively comlete digestion and gas conversion, but 15 to 20 days has been found adequate for most manures. A 20-day retention means that a digester must be large enough to hold 20 days' production of manure, urine, and flush or dilution water.

Influent solids concentration refers to the percent dry matter of *total solids* in the slurry. Control of solids concentration is needed to maintain consistency in the loading rate and to facilitate material handling—especially pumping. Dilution with water is usually required, although thickening through settling may be called for with systems using a great deal of water during cleaning operations. The amount of dilution water needed, whether added during floor flushing or in a mixing tank located ahead of the digester, depends in part on manure type. Poultry manure, for instance, is not only very dry compared to other manures (about 25% dry matter versus 13% for cattle), it is relatively high in nitrogen and ammonia, requiring it to be more dilute for good digestion. Because it starts out quite dry and needs to become very wet, a relatively large amount of water must be added to and thoroughly mixed with poultry manure prior to digestion. For a given size digester, an increase in dilution water volume will reduce the retention time; conversely, if retention time is to be maintained, digester size must increase in accord with the amount of dilution water used.

The loading rate refers to the rate at which organic solids are fed to the digester. About 80%-90% of the dry matter is organic and subject to bacterial decay. The technical term for organic matter is *volatile solids*, and loading rates are measured in terms of pounds of volatile solids added each day to each cubic foot of digester volume. Experience has shown that loading rates must be limited according to the degradability of a particular manure. For example, about 0.4 lb of volatile solids per cubic foot per day is the recommended maximum for cattle manure. This means that each cubic foot of digester space should receive (be loaded with), on the average, no more than 0.4 lb of volatile solids per day. Digester volume, then, must be large enough to assure that the recommended loading rate is not exceeded, in addition to meeting the volume requirement based on retention time. Additionally, digesters with separate storage containers should be oversized by about 10% to preclude plugging of gas lines by digesting solids or foam.

It is debatable how small a farm operation makes sense for biogas production, but digester cost per unit volume clearly decreases as size increases. For manufactured tanks the scale efficiency actually occurs in steps, since a limited number of tank sizes are available. Within reason, an advantage of buying a larger-than-necessary tank lies in the capacity available for future expansion, for digesting farm wastes other than manure, or even for capitalizing on the disposal needs of a neighboring farm.

Effect of Digester Temperature on Rate of Gas Production



Gas Handling and Storage

Biogas must be delivered to the equipment using the fuel as cheaply and safely as possible. The methane component of biogas is not only flammable but can be explosive when mixed with air in concentrations of 5%-15% methane. The same safety precautions taken for natural gas applications should be applied to the biogas delivery system.

Special care is necessary in closed buildings or compartments where leaks could lead to gas accumulations. Whether or not required by local safety codes, ventilation fans and explosion-proof lights and motors should be considered. Alarms and easily accessible shut-off valves should be built into the system, and flame arresters should

A SIZING EXAMPLE

Assume:

1. Wastes collectible from 300 dairy cows
2. Each head produces 1.8 ft^3/day of wastes containing about 15% TS (total solids) fresh. This converts to 16.8 lb TS per day per head (1.8 ft^3/day × 62.4 lb/ft^3 × 0.15 = 16.8 lb/day)
3. The maximum influent solids concentration (TS) is 12%
4. VS (volatile solids) equal 80% of TS
5. Each day 133 ft^3 (995 gal) flush and dilution water is added
6. The maximum desirable loading rate is 0.35 lb VS/ft^3·day
7. The minimum desirable retention time is 15 days
8. Digester capacity should be 10% oversized to allow for gas collection

Data Summary

Volume/day: 300 Head × 1.8 ft^3/Head	=	540 ft^3
Dilution		133
		673 ft^3
Weight/day: 673 ft^3 × 62.4 lb/ft^3	=	41,995 lb
TS Produced/Day: 300 Head × 16.8 lb/Head	=	5040 lb
TS in Slurry: (5040 lb − 41,995 lb) × 100%	=	12%
VS Produced/Day: 5040 lb × 0.8	=	4032 lb

Find:

1. The required digester capacity and resultant retention time based on the specified loading rate maximum.
2. The required digester capacity and resultant loading rate based on the specified retention time minimum.

Solution:

1. Digester capacity required $= \dfrac{\text{Daily VS}}{\text{Loading Rate}}$

$$= \frac{4032 \text{ lb VS/day}}{0.35 \text{ lb VS/day}\cdot\text{ft}^3} = 11{,}520 \text{ ft}^3$$

Resultant retention time $= \dfrac{\text{Capacity}}{\text{Daily Volume}} = \dfrac{11{,}520 \text{ ft}^3}{673 \text{ ft}^3\text{/day}} = 17$ days

2. Digester capacity required = Daily Volume × Specified Retention Time
= 673 ft^3/day × 15 days = 10,095 ft^3

Resultant loading rate $= \dfrac{\text{Daily VS}}{\text{Digester Capacity}} = \dfrac{4032 \text{ lb VS/day}}{10{,}095 \text{ ft}^3} = 0.40$ lb VS/day·ft^3

Conclusion: 11,520 ft^3 is the capacity required (unless a higher loading rate can be tolerated)
Add 10% for gas collection - 1152 ft^3
The total digester capacity required is 12,672 ft^3

Try This Exercise: If a 25,000 ft^3 digester were built in order to accommodate possible future expansion, what would be the loading rate and retention time while operating with the present 300 head?*

Solution: Volume assumed available for digestion = 20,000 ft^3/1.1 = 18,182 ft^3

$$\text{Loading rate} = \frac{4032 \text{ lb VS/day}}{18{,}182 \text{ ft}^3} = 0.22 \text{ lb VS/day}\cdot\text{ft}^3$$

$$\text{Retention time} = \frac{18{,}182 \text{ ft}^3}{673 \text{ ft}^3\text{/day}} = 27 \text{ days}$$

*Assuming full use of the excess capacity, which would not be necessary.

be used to prevent backfiring from water heaters and other equipment.

The digester should be equipped with a pressure gauge and a provision for pressure relief. This can be in the form of a regulator or a simple combination of pipes holding a column of water to provide a liquid seal (like in a toilet). Although excessive pressures can be relieved by simply venting to the outdoor atmosphere, high flow rates of excess gas should be burned with a flare.

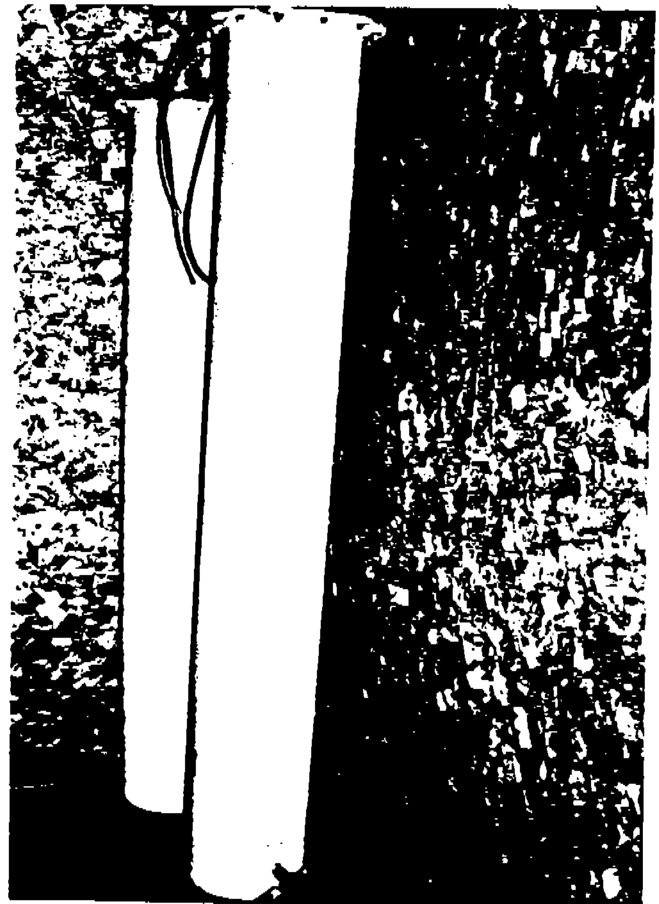
Even routine maintenance of biogas equipment can be hazardous for careless or untrained operators. For example, a gauge pressure of only 1 psi would indicate a force of 450 lb against a 2-ft-diameter access cover. Loosening the cover without first relieving the pressure could be dangerous. Also, because methane is lighter than air, it has a habit of sneaking into upper cracks and recesses, mandating special care during cleaning operations.

Biogas always contains some water vapor, so the gas handling system must be designed to preclude corrosion, condensation blockages, and freezing. Sloped lines, condensation traps, and proper pipe materials and sizing should provide adequate protection depending upon climate and gas flow rates.

Biogas normally contains traces of hydrogen sulfide (H_2S), a corrosive impurity which may require removal if sulfuric acid formed by its combination with water vapor poses problems for appliances or equipment operating on biogas. H_2S precludes the use of copper gas lines. Rigid copper piping requiring sweat joints has always been taboo in the natural gas business, and recent experience has shown that even flexible copper tubing should not be used with biogas. H_2S can literally eat its way through the lines.

Improper selection and installation of piping is notoriously dangerous. Black iron, heavy-wall brass, or manufacturer-approved flexible polyethylene (PE) pipe is recommended for biogas lines. Approved flexible PE (orange in color) uses either fusion welds or compression couplings and is tougher and more resistant to thermal cracking than (even Schedule 40) PVC pipe. Many installers have had no problems using ordinary PVC or CPVC for transporting biogas—in fact, even garden hoses have been used by some reckless souls—but the hazards deserve acknowledgment.

Technically, no type of plastic pipe is approved for use inside buildings. According to the International Conference of Building Officials 1979 Uniform Mechanical Code, as well as the 1981 National Fuel Gas Code sponsored by the American National Standards Institute and the National Fire Protection Association, use of PVC or PE plastic piping should be restricted to exterior, underground installation. Advised interior use of plastic lines may, in some cases, be perfectly safe, but for those contemplating such use, consultation with a local building safety official is recommended to determine possible risks and liabilities.

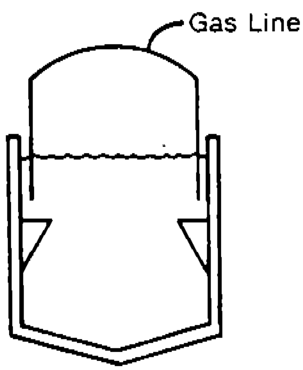


Series-connected H_2S scrubbers made from 10-inch steel pipe. Photo: H. Lapp

Although H_2S is generally considered detrimental to engines, the effect may not be as serious as once anticipated, except in the case of manure from animals on high-sulfur drinking water or feed rations. Continuous engine operation poses less of a problem than intermittent, which encourages condensation of biogas vapors. H_2S content can be reduced, in any case, by directing the biogas through an iron sponge reactor or scrubber. The scrubber is essentially a container filled with wood shavings and rusty iron filings, requiring carefully controlled, periodic regeneration by exposure to air.

Biogas storage can be a nuisance because huge storage volumes are necessitated by the relatively low energy value, and liquefaction is impossible at reasonable temperatures and pressures. Ideally, biogas usage should match production to minimize the need for storage, but usage rates are bound to vary day to day and season to season, so some storage capacity is essential.

Collection and low-pressure storage chambers include rubber or plastic bags resembling giant pillows. The same idea is represented by the covers used over some plug flow, in-ground digesters. An alternative gas collection low-pressure storage scheme is to use a floating cover set up either as a floating roof in the digester or in a separate container of water. The principle of the cover can be represented by an upside-down coffee can floating in a sink. If the can is weighted to keep it down, it will rise or sink as air is let into or out of the enclosed space. In a biogas application, a 5- or 10-ft-diameter cover will need to be heavily weighted, if made of a light material like fiberglass, or may even need to be counterweighted if made of steel. The overall weight controls the pressure at which biogas is supplied to the equipment or appliances. A few inches of water pressure is adequate to deliver the gas over short distances. Floating covers are compact and durable but tend to be much more costly than auxiliary bags or tanks for other than very short-term storage.

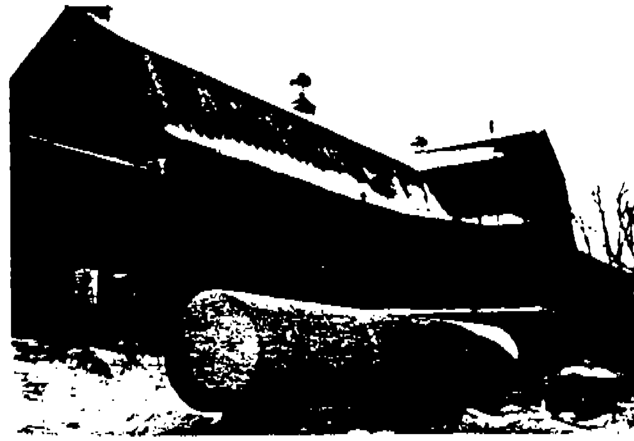


Cutaway Sketch of a Floating Cover Collector

Whatever the container, low-pressure storage for more than a few days of gas production is not practical. One day's net production, for example, will fill a space up to double the size of the digester itself. Production and usage rates must, therefore, be carefully balanced to assure full use of all gas produced. Limited, longer term storage can be achieved at medium pressures by using propane tanks. Storage volumes can be reduced by a factor of about 15 by pressurizing to 200 psi with a conventional, corrosion-resistant cold storage compressor. Pressurizing to much higher than 200 psi without special equipment, however, is expensive and dangerous. Even with low-pressure storage, pressure relief valves should be strategically located to prevent dangerous, above-design pressures during periods of reduced gas demand or equipment downtime.

The special requirements for safety and reliability of the gas handling system point to the need for knowledgeable, experienced help in design and fabrication. Poorly built digesters can waste money, but poorly built gas handling systems can waste lives.

Inflatable 14,000 ft^3 cover for gas collection and one-half day's storage over inground plug flow digester. Mason Dixon Farm Dairy, Gettysburg, PA.



10,000 gallon pressurized railway car tank used for biogas storage. Wayne Gibbons Poultry Farm, Ripon, WI.

1300 ft^3 inflatable gas storage bag. University of Missouri at Columbia.

Biogas Yields and Uses

Production Rates

Every farmer with an interest in this subject naturally wonders, "How much biogas could my operation produce?" There are many variables involved, so estimates based strictly on type and number of animals are risky at best. Values in the accompanying table of approximations should be tempered according to information known about a specific operation. Daily production of manure solids varies with climate, animal diet, activity, and life cycle position. Manure age and collection practices also affect gas production. Fresh manure, for instance, will produce more biogas than aged manure.

The variation in gas production estimates between different species is explained primarily by two factors. First, some species pass a weight of volatile solids each day which is greater in proportion to body weight than do other species. Thus, while a ton of chickens produces a lesser weight of raw manure per day than a ton of calves, the dried weight of volatile solids is greater from the chickens. Second, bacteria find it easier to decompose volatile solids in some manures than others. Bird volatile solids, in particular, are very good gas producers. The overall effect is that poultry have the potential for producing relatively high biogas yields. Biogas production from poultry manure poses a number of problems, however, including control of scum, ammonia, and settling in the digester.

Animal type	Daily output Per 1000 lb (ft^3)	Assumed weight per animal (lb)	Daily output per animal (ft^3)
Dairy cattle	44	1350	59.5
Beef cattle	40	900	36.0
Hogs	39	200	7.8
Poultry (layers less than broilers)	100	4	0.4

NOTE: These estimates represent a composite from various researchers and should be used with caution. Reported yields vary widely. Some data shows beef yields higher than dairy, for example. Individual results depend considerably upon feed ration and manure collection practices.

Laboratory analysis of samples collected under planned conditions is recommended for farmers needing more accurate yield estimates, for example for performing economic analyses of biogas production equipment.

Estimated Biogas Production Rates

The biogas production rates estimated in the table represent gross rates. From 20%-50% may be needed for digester heating, depending upon manure gas productivity, climate, season, effectiveness of digester insulation, and system design. Larger digesters are more efficient heat retainers than small ones because of their lower surface-to-volume ratios. In fact, very small digesters such as 55-gal drums could require more gas for heating than they produce. As discussed previously, solar water heaters, influent preheating, and engine heat recovery can help reduce the fraction of biogas consumed for digester heating.

Consistency is the key to stable production rates. Digester bacteria like a nice, steady diet, free of the many substances known to inhibit or kill bacterial action. For example, manure from animals on therapeutic doses of antibiotics should be diverted from the digester, as should wash water following major disinfecting operations. Another important factor is pH. In a properly functioning and managed digester, pH is usually self-controlled between about 7.0 and 8.0, but such disturbances as toxic elements, temperature fluctuations, and heightened loading rates can upset the balance between acid forming and methane-forming bacteria. The pH may then drop as the relatively tolerant acid formers begin to outproduce the sensitive methane formers, lowering the ratio of methane to carbon dioxide in the biogas or even terminating gas production altogether. An astute operator should be able to correct a deteriorating condition before it becomes too serious, however. The CO_2 level can be monitored with an inexpensive measuring device. Also, foul odors and diminished biogas yields are effective advance warning signals.

Gas Use Choices

What is the best use of biogas? There is no one answer to this question. Every situation is different, so a farmer contemplating an installation should consider needs carefully. Some of the possible uses are:

Farm
Grain drying or grinding
Irrigation engines
Pen heating
Ethanol still heating
Dairy water heating
Electric power production

Household
Space heating
Water heating
Cooking
Refrigeration
Clothes drying
Air conditioning

Direct Burning—General Considerations

Direct burning of biogas for space heating, water heating, or steam production is probably the most energy-efficient use, if production and usage rates can be reasonably balanced within a range accommodated by storage capacity. Conversion of equipment is simple, and provisions for a backup fuel such as propane can easily be made. Caution is advised, though. With the H_2S intact, biogas is poisonous and quite corrosive to intermittently operated gas burners and vent stacks, potentially leading to unannounced exhaust leakages. Scrubbing is therefore recommended for biogas used in living areas. It is worthy of note, incidentally, that although pure methane gas is not poisonous it is suffocating.

When farm applications take precedence, there often is not much gas left over for household use. A simplified household example is easy to relate to, however, and may help put usage rates into perspective. Assume that a year-round average of about 600 ft^3 (600,000 Btu) of natural gas per day would supply a northern home with heat, cooking fuel, and hot water. About 1000 ft^3 of biogas per day would be needed for the same use. Assuming one dairy cow could produce about 60 ft^3 of biogas per day, and that about 40% of gross production would be required for digester heating, about 25-30 cows could produce a net amount of 1000 ft^3 of biogas per day. Average figures can be misleading, however. One-thousand cubic feet would be more than is needed during August and less than is needed during February. Since storage of large amounts of gas is impractical, a larger number of cows would be required during the cold months.

Although the number of cows—or hogs, horses, or turkeys—required for various tasks can be estimated, piecemeal planning of biogas uses should be avoided. The best way to plan biogas uses is to inventory and prioritize all farmstead and home energy demands and fluctuations first, and then to select those applications that make the most sense. The most appropriate and cost-effective uses should be matched with anticipated gas production and storage for each individual situation. No two farms or families have exactly the same energy needs or preferences.

There is growing interest in the use of biogas as boiler fuel for ethanol stills, which require large amounts of steam heat for the distillation process. Although there is no combination digester-still known to be in operation at this writing, several are in the planning stage.

Use in Vehicles

Biogas use as vehicle or equipment fuel is in most cases not practical because of the large tank sizes required; however, biogas has been resorted to as a short-range motor fuel during supply shortages, such as in Europe during World War II. Entire fleets of autos are now operating on compressed biogas derived from sewage treatment in the cities of Modesto, Calif., and Milan, Italy. Compressed methane made from natural gas is readily available in this country from bottled gas suppliers and is being used experimentally in fleets of vehicles in some communities, including Greeley, Colo. Three hundred cubic feet of gas can be squeezed into a 52-in. long, 9-in.-diameter cylinder at 2,265 psi. Five of these cylinders would give a farm pickup a range of perhaps 150-300 miles on methane or 90-180 miles on biogas. The Beech Aircraft Co. in Boulder, Colo., has developed a low-temperature (-260°F) liquefied methane storage system offering a 600:1 volume reduction at only about 30 psi in a trunk- or bed-mounted, 18-gal tank installation for cars and trucks. Liquid methane (not biogas) provides about 90% of the mileage of gasoline, and the octane is much higher (125-130 versus 84-97), offering a performance advantage in modified, high compression engines. The cost of on-farm separation and liquefaction of methane is prohibitive at this time for the average farmer, but the economics will improve with continued development and ever-increasing gasoline prices.

Power Production

Engine-Generator Sets. Stationary engines for equipment power, irrigation, or electricity generation offer the best use for biogas on some farms. Electricity generation, in particular, is expected to become more common, especially when conversion losses can be recovered as heat. The most obvious candidates for conversion to biogas are emergency engine-generators which many farms already have set up in standby mode to provide lighting and to operate circulation fans in hen houses or other critical equipment in case of power failure. The gasoline engines typically used can be converted to run on 100% biogas and, if biogas is available, an attempt at full-time electricity production may be tempting. This may be ill-advised on several grounds, however. The system may not be designed for full-time operation at the required capacity. If the engine is air-cooled, use of waste heat for digester heating is more difficult if not precluded, although space heating may still be possible, and savings in electrical costs may be less than available from other biogas uses.

There are inexpensive choices for small or low-income farmers wanting to produce electricity from biogas. Old tractors or tractor engines make good power units, for example. The key to overall efficiency is to put the engine heat to good use. A relatively cheap and efficient system results from coupling a generator of appropriate capacity to a used tractor or truck gas engine inside a building requiring heat, with a long exhaust pipe running outside. Piping should be connected to allow engine cooling water to be used for digester heating. If the engine is large relative to the digester volume, parallel lines and an inexpensive thermostatic control may be called for to prevent overheating digester contents.

In addition to the generator which should be available for about $2000 depending on size, the farmer would need to purchase a gaseous fuel carburetor system (about $500) and a speed sensing electronic governor (about $300) to precisely maintain engine speed in accordance with the generator specification. If propane is to be made available as a backup fuel, a diaphragm vaporizer (about $75) will also be required ahead of the carburetor.

For larger operations where investment in a heavy duty used or new diesel or gasoline engine-generator set is being planned, consideration should be given to the relative advantages and disadvantages of diesel versus spark-ignited engines (a diesel fitted with spark plugs and lower compression heads or pistons is not considered a diesel in this discussion). Spark engines offer an advantage in that they can run on 100% biogas and be set up to switch to propane automatically. Because of their lower compression ratios, however, these engines achieve less power output than comparable diesels, turning a higher fraction of fuel energy into heat. In some cases, though, the extra heat may actually be of more value than the extra power. Operation on biogas will necessitate derating of any engine-generator set, and the power unit should be carefully selected to assure normal operation at near full capacity. The trade-off in excessive oversizing to accommodate power surges is a great loss in both engine and generator efficiencies.

Dual fuel conversions are manufactured for diesel engines which allow operation on a mixture of biogas and diesel fuel. Diesels cannot run satisfactorily on straight biogas or even straight methane because a small percentage of oil is necessary for sparkless ignition. This means the injectors must be retained, and these require a larger flow of oil to prevent scoring. Operation of dual fuel diesels on drilling rigs has traditionally been on a mixture of about 85% natural gas (by energy content, not volume) and 15% diesel fuel, switching automatically to up to 100% diesel fuel in cases of gas supply interruption. Operation on a higher percentage of methane or biogas is possible, maintenance implications aside, although with biogas, engine efficiency and power output are lowered because of the noncombustible carbon dioxide component. Under variable loading conditions, such as typically found in farm operations, the dual fuel system responds to load increases by supplying an increased diesel fuel flow rate sufficient to meet the power demand.

From an energy efficiency standpoint, in terms of power output as a fraction of fuel input, the dual fuel diesel is superior. With its 17:1 compression ratio, it will outperform any spark-ignited, normally aspirated engine limited to a compression ratio of around 12:1. High loading conditions, however, may require heavy consumption of diesel fuel. From a cost efficiency standpoint, therefore, a spark-ignited engine may be superior, depending upon biogas availability, CO_2 content, loading conditions, and the price of fuel oil. Several manufacturers offer high compression spark-ignited engines which can take advantage of methane's high octane rating by advancing ignition timing about 20 degrees. These engines can be supplied with generators, propane backup fuel systems, heat recovery systems, and other desired accessories. Compromise may be necessary, though, if much propane use is anticipated.

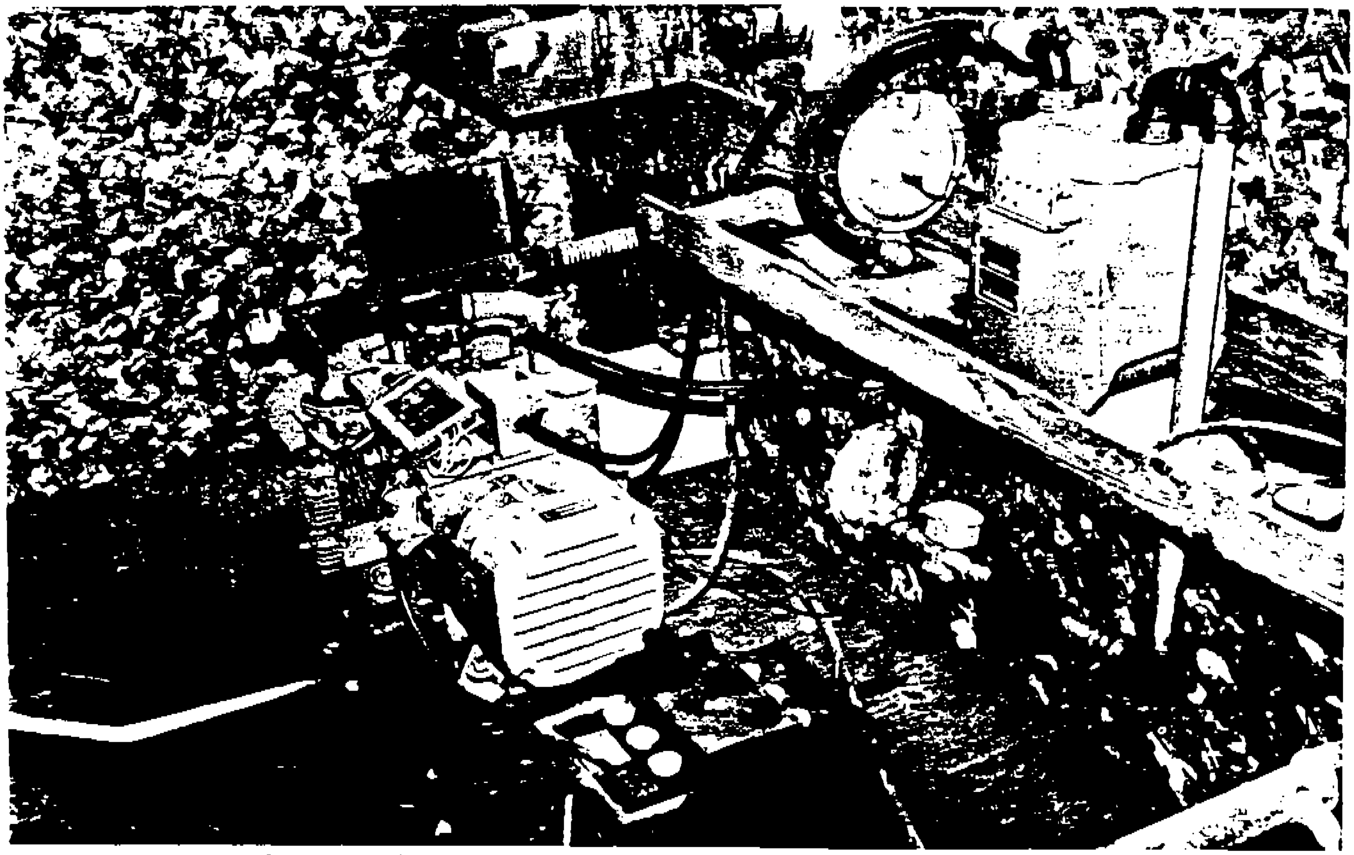
A compression ratio high enough to capitalize on methane (10-12:1) is too high for full load or continuous running on propane, even if the timing is retarded when the propane is switched on. For other than occasional, reduced-load propane use, therefore, a lowered compression ratio may be recommended, and this carries a loss in efficiency when operating on biogas.

An Italian manufacturer, Fiat, best known for their cars, is producing a small engine-generator set in a neatly packaged 4-ft × 4-ft × 4-ft "total energy module" called the Totem. The engine is a 127-cc 4-cylinder, which hums along at 3700 rpm, providing a maximum of 15 kW of electrical power along with 131,000 Btu/hr of heated water from a very efficient heat exchanger system. The Totem is an attractive package for operations able to use the output levels of both electricity and hot water. Four modules are currently undergoing testing by New York's Brooklyn Union Gas Co., which is acting as Fiat's liaison in the United States.

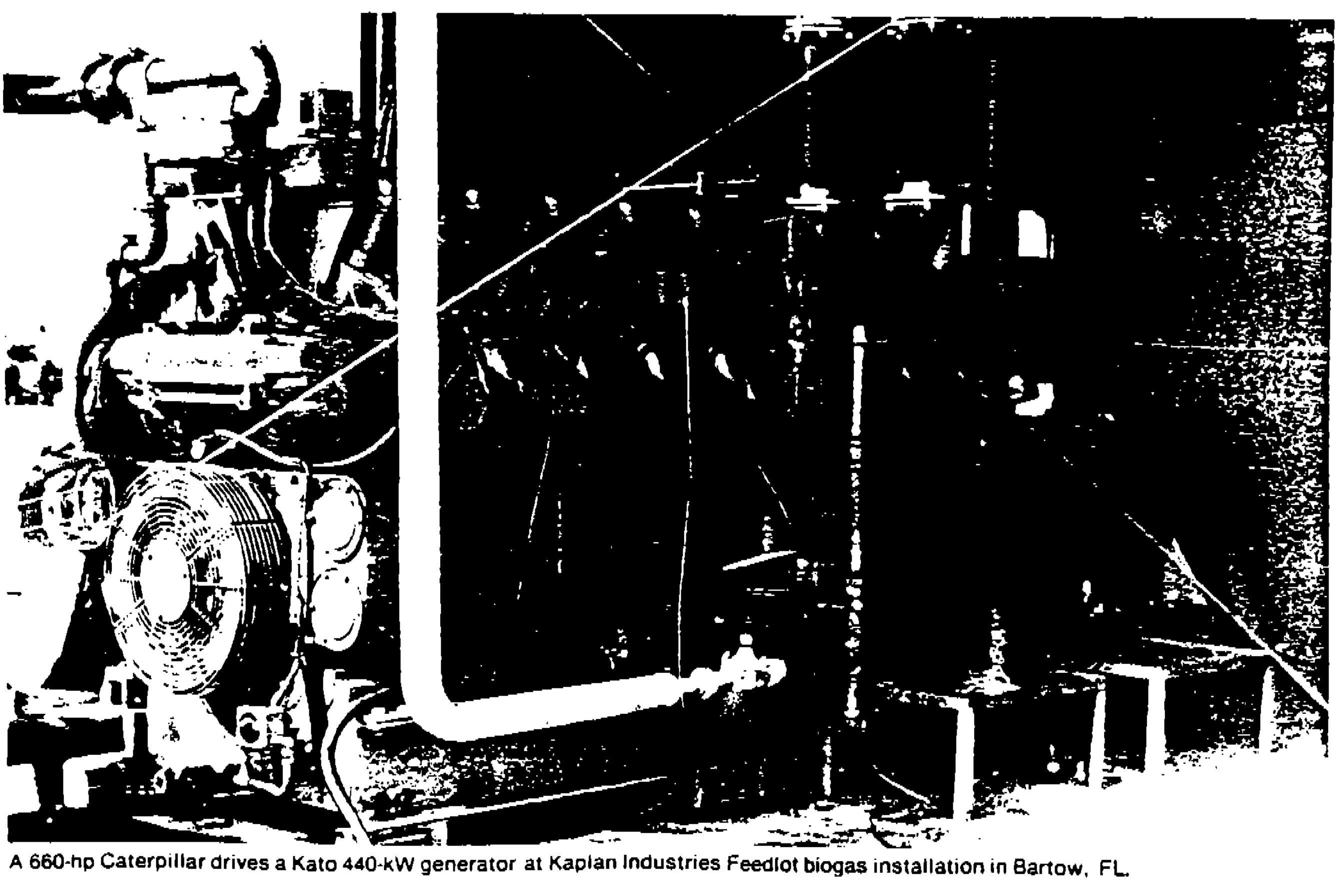
The use of farm-produced electrical power may require a number of operational changes to take advantage of the power on-site. Kilowatt-hour usage should be plotted to determine where load leveling might best be applied, to help spread usage rates as evenly as possible throughout the day and seasons. There are many operations, such as silo unloading, which can be scheduled by automatic timers. Also, peak power for bulk tank cooling can be reduced by precooling a water bath "off peak" and using cold water to precool the milk before it enters the bulk tank. These are merely examples. The farmer aiming for power production should consider every innovative conservation practice possible to stretch the electrical energy budget supported by the biogas system. Also, in high-wind areas, consideration should be given to integrating the biogas power system with a wind power system.

Sale of Electricity. Although on-farm use of biogas-generated power should have first priority, many operations have the potential for producing an excess of biogas-generated electricity. Sale of this excess energy to a local utility may in some cases be an option which should be considered during planning for a digester installation. Partly because of governmental urging, utility companies are increasingly receptive to purchase contracts for electricity produced in excess of need by private individuals or firms. New Federal Energy Regulatory Commission regulations, issued in ac-

Engine Generator Sets Come In All Sizes



A modified 10.2-hp, 4-kW Onan is one of two operated experimentally at the University of Manitoba's Swine Research Complex.



A 660-hp Caterpillar drives a Kato 440-kW generator at Kaplan Industries Feedlot biogas installation in Bartow, FL.

cord with the Public Utilities Regulatory Policies Act (PURPA), provide that under certain circumstances private energy producers shall be credited or paid by the local utility for electricity delivered to the utility. The law requires the payment rate to reflect costs avoided by the utility not only for electricity delivered (energy in kWh), but also for the excess capacity (power in kW) shown to be available from a producer's generating plant.

The concept of "capacity credits" is already reflected in some contracts which provide higher prices per kWh to private producers for energy delivered at a time of day when it is most needed by the utility grid system. Fortunately, the ability to store biogas allows the farmer to generate on any desired daily time schedule. Yet, the most favorable energy rate or capacity credit consideration can be granted by utilities only to private producers capable of providing worthwhile amounts of continuously available, reliable power. A large biogas-powered generating plant located near a major feedlot could qualify for preferred rate treatment. Serving as a preferred rate power source for a utility may also prove workable for smaller farmers joined in energy district cooperatives. Several interesting options exist.

Generator Options for Power Producers

A brief discussion of equipment is offered because of the anticipated popularity of power generation. Two types of alternating current generators can be used by farmers interested in selling excess electricity to their utility companies. Standard farm standby or auxiliary engine generator sets use synchronous generators. These normally are used only to provide for on-site demand and are not interconnected with the utility system. If interconnection is desired, the utility will require a safety switch or fail-safe interlocking device accessible to their line crews so that during utility power failures or maintenance operations workers can service lines without fear of backfeeding from scattered small producers.

Paralleling and synchronizing equipment is also necessary to assure that the farm power unit can come "on line" at 60 Hz and is in phase with the grid. Cost estimates for paralleling and synchronizing equipment are now readily available from suppliers as a result of the heightened interest in power generation encouraged by PURPA.

The alternative to the parallel system synchronous generator is the less common and less expensive induction generator, which actually is a motor. The apparent double talk results from the fact that a typical squirrel cage induction motor literally becomes a generator under special operating conditions. Picture a utility-power-driven electric motor connected to the power take-off shaft of a biogas-fueled tractor chassis. By engaging the tractor clutch, the motor can be used to start the engine. Now imagine the engine speed being increased gradually to the synchronous speed of the motor—say 1800 rpm. The motor is now just spinning under a no-load condition. Engine and motor speed continue to climb. Suddenly current begins to flow back through the lines from which it came; the motor has become a generator. Current output now rises in proportion to engine-generator rpm, up to the generator's power rating. Overspeed is controlled by the engine's calibrated governor. In this simplified example, the engine-generator set has become part of the utility grid. If generator output exceeds farm system load, the kWh meter runs backwards (unless racheted) and, in effect, the farm is selling electricity to the utility—with no synchronizing equipment whatever.

This is all possible because the utility is providing magnetic excitation of the generator's windings. Frequency is fixed at 60 Hz, and voltage is constant at 115 or 230 V depending on how the generator is wired. But what happens if the utility power goes off for more than a few seconds? Capacitors can be set up to sustain short or even long duration outages, but frequency and voltage control for varying load conditions is a very tricky business. The practical alternative during blackouts is to switch off the utility connection (company linemen will check to see that this has been done) and resort to auxiliary power. Herein lies a disadvantage of the induction generator as compared with the synchronous generator. A synchronous generator could in this situation continue to supply farm demand independent of the utility system. However, most farms already have reduced-capacity auxiliary power systems. Moreover, a smaller, appropriately equipped gasoline engine-synchronous generator can be used to provide the required magnetic field to allow continued operation of the larger induction generator at any desired loading. Elaboration on the pros and cons is not possible here, but the advantages of induction generators should be investigated by farmers contemplating small power producer status.

Because of PURPA, every utility company in the United States is now attempting to arrive at fair wholesale rates for customer-generated electricity. The respective state public utility commissions are holding hearings in an effort to assist in arriving at these rates. Final determinations on formulas may not be available until Summer 1981.

A wholesaling agreement normally calls for use of an extra kWh meter—possibly fitted with a clock to allow time-of-day credits. One meter records retail energy delivered to the customer; the other records wholesale energy supplied to the utility whenever the customer is generating more than is being used. The alternative to the dual meter wholesaling arrangement is for the utility to simply allow the (single) meter to run in both directions. This is the present practice of several utilities that have windmill generators connected to their systems. In these cases, the customer is in effect being credited at the retail rate for energy generated. The utility does not owe the customer, though, if one month's meter reading turns out to be less than the previous month's reading.

If the utility allows the customer to choose between single and dual metering, the choice should be based upon expected generation levels. A comparison of the ratio of retail to wholesale price with the ratio of excess kWh generated to kWh used would indicate the better choice. However, in some states it may turn out that neither the customer nor the utility can make such choices. The rules should be clearer by mid 1981.

Power Production Examples. Research at the University of Missouri at Columbia, where agricultural engineers have operated a full-scale hog manure digester since 1976, has shown that energy self-sufficiency is possible for confinement pork production operations. A Waukesha gasoline engine-generator set was selected for study, partially because the engine offered an ideal heat output to power output relationship for this particular application. Calculations showed that all of the electrical energy as well as all of the heat energy—down to about 28°F outdoor temperature—could be provided by biogas for a pork production facility marketing 3200 hogs per year.

A good example of a private biogas installation successfully producing electricity can be found at the Mason Dixon Farm near Gettysburg, Pa. The farm has about 1200 Holstein milkers, plus 500 heifers and calves, with the sheltered loafing pens arranged so manure can be collected from the majority of the herd. Twice daily, manure is flushed from the pen floors into a settling basin, where water drains off until the slurry reaches about 12% solids. It is then moved into a mixing basin where it is inoculated with some digester effluent, and then pumped into one of two concrete pit plug flow digesters. The original digester, built in Fall 1979, has a capacity of 200,000 gallons and is covered by a collection bag which provides storage for about one-half-day's gas production. The second digester has a capacity of about 260,000 gallons and was completed in December 1980. The newer digester is topped by a hypalon rubber cover but operates by design at a slight vacuum, leaving the system to rely on the first digester for gas storage capacity. Over 2.5 million ft^3 per month of biogas production is expected when operation of the new digester becomes stabilized in Spring 1981.

The biogas is used to power a Caterpillar spark-ignited diesel connected to a 150-kW syncronous generator. The system already provides 100% of the electrical energy used on the farm (not including the dairy).

Metropolitan-Edison Co., the local utility, has expressed interest in buying excess energy from the farm at 3.5 ¢/kWh. Farm Manager Richard Waybright is also considering building an ethanol still with steam heat for the still to be provided by an exhaust manifold heat exchanger on the diesel. As envisioned, the alcohol system would have the capacity to convert 30,000 bushels of corn per year into 75,000 gal of nearly 200-proof pure spirits, currently selling at about $2/gal for use in making gasohol.

Kaplan Industries, Bartow, Fla., operates a large U.S. Department of Energy (DOE) sponsored digester facility built by Hamilton Standard. The installation currently processes waste from about 6000 cattle and has a capacity to accommodate wastes from about 10,000 head. In addition to other uses, biogas produced by two thermophilic digesters is used in part for power production. Three-phase power is produced by a 440-kW Kato generator driven by a 660-hp Caterpillar engine. Electricty generated is fed into the local power grid in cooperation with the Florida Power Corporation. A study is underway to evaluate the technical and economic aspects of electrical power production from a small biomass source.

Off-Farm Use of Biogas

In cases where waste engine heat cannot be used, or where electricity production from large amounts of excess gas is for any reason not feasible, sale of the gas for off-farm use may be an alternative. Cooperating networks of farmers could supply purified biogas as a substitute for natural gas for industrial or residential users miles away from the digesters. This alternative may be limited, though, to local areas where pipelines are already accessible. Metering devices, incidentally, can account for the simultaneous use of more than one variety (and Btu-value) of gas in a pipeline.

Some private utilities have been quick to recognize the potential for commercial biogas production. The Southern California Gas Company and Pacific Gas and Electric Company are jointly sponsoring a biogas demonstration plant placed in operation in 1978 on the Kershaw and Sons' feedlot in the Imperial Valley near Brawley, Calif. The project has two objectives: to investigate the technical and economic factors involved in producing biogas from cattle manure, and to establish the value of digester residue as a livestock feed ingredient. Economic and environmental studies are now underway to determine the feasibility of a commercial-size biogas plant.

Calorific, Inc., a subsidiary of Thermonetics, Inc., of Oklahoma City, was the first company in the United States to obtain federal clearance to introduce methane produced from feedlot wastes into the interstate pipeline system. In what is known as the Calorific Recovery Anaerobic Process, or CRAP, two 2.5-million-gal mesophilic digesters at the company's Guyman, Okla., plant are supplied daily with 500-600 tons of raw wastes collected from about 100,000 cattle. Any desired fraction of the biogas produced can be upgraded to pure methane, and during 1978 methane was sold for transport and use in the city of Chicago, about 800 miles distant. A company spokesman indicated in August 1980 that some mechanical difficulties with CRAP had been resolved and that although process-use of the gas had first priority, sale of excess gas to the interstate system had been retained as an option for the future.

Making methane from excess biogas available for off-site uses represents not only an opportunity for the producer but is in the national interest as well. Industry demand for gas already exceeds availability in some areas, and an increased, inexpensive supply would motivate a proportional conversion from foreign oil. Many companies are now forced to limit gas consumption by utility company agreement and in some cases to switch to oil during supply interruptions. Gas distribution networks are not as universally available as electrical distribution lines, but increased availability of natural gas substitutes from farm, municipal, and other wastes as well as from coal is expected to bring about some expansion in the national gas distribution system.

Whatever the immediately apparent needs or opportunities might suggest, farmers considering or already operating biogas plants are challenged to make as full and productive use of the gas as possible.

Benefits Beyond Gas

The primary focus of this booklet is energy savings available through biogas production. Anaerobic digestion offers other benefits, however, somewhat dependent upon the sort of operation one starts with. Some of these benefits are of an environmental nature, while others can potentially be translated directly into dollar savings.

Anaerobic digestion makes disposal, storage, or use of manure easier and more pleasant. Improved homogeneity and viscosity make for easier pumping to tanks or pits. Digested manure also has less odor and is not as attractive to flies. Mason Dixon Farm personnel attribute a nearly total elimination of manure odor to their digester installation and consider this to be one of the system's most important benefits. Digestion also kills many weed seeds, as well as several species of pathogenic bacteria, including salmonella, and some viruses. Digester effluent is not suitable for discharge directly to streams or watersheds, but its pollution potential is less than that of unstable raw manure because of a reduced chemical oxygen demand. Requirements for additional predisposal treatment to meet abatement standards thus may be lessened.

A promising new use of effluent fiber is for bedding material. Fibers in fresh manure may be 2 in. or so in length, whereas digested fibers are only perhaps 1/2-in. long. These are left as residue when moisture is forced out of effluent with a press. They look rather like chewing tobacco, are quite spongy, and have no odor since the bacteria die on contact with air. The nutrients in the liquid separated from the fibers can still be used as fertilizer, and the bedding can be run time and again through the digester. The Mason Dixon Farm uses a Surge press to squeeze its digester effluent down to about 68% moisture content, discharging the liquid to a pond where it is stored until needed for seasonal land application. The somewhat soggy, fibrous material is spread on a screen and dried further by passing ambient air and hot exhaust from the generator engine through the accumulation. The farm manager reports satisfaction with the residue as recyclable bedding material, emphasizing that no mastitis or other health problems have been experienced.

Drying bin with screened floor to allow forced drying of separated digester effluent. Mason Dixon Farm Dairy, Gettysburg, PA.

Fertilizing with Digester Effluent

Studies have shown that no fertilizer elements (N, P, K, etc.) are lost during anaerobic digestion. In fact, the quality of the effluent, in terms of its stability and availability to plants, may be somewhat increased because the organic nitrogen has already been converted to inorganic forms. When fresh manure is applied to soil, organic nitrogen must first be broken down by bacteria, initially competing with crops for certain nutrients, and possibly being washed or leached away before the conversion is complete. Also, nitrogen in fresh manure may volatilize as ammonia and be lost to the atmosphere before plants can use it. Generally, a digester—or any closed tank—can help to prevent nutrient losses that occur through seepage or volatilization to the atmosphere with open pit storage.

Fertilization benefits will actually depend more upon storage, application technique, and timing than upon digester inclusion in the overall manure handling system. If, for example, a farmer already has a slurry storage or well-designed anaerobic lagoon system and liquid injection equipment in operation, the potential benefits will be less than for a farmer who does not already have a good manure utilization program.

Clearly, the primary fertilization benefit of anaerobic digestion lies in increased nitrogen availability, the exact value of which is difficult to estimate. Whatever benefits do exist can be lost, of course, with poor planning or careless spreading or spraying practices. Laboratory tests of effluent should be performed to determine nitrogen content, and decay constants should be considered in estimating fertilizer replacement values or application requirements. Optimum application

Laboratory analysis of effluent is recommended to determine concentration of nutrients. Potential fertilizer value can then be estimated and in turn used in assessing investment options for storage facilities and utilization equipment. In the example below, sample lab test results are shown for the primary nutrients. Illustrative calculation of fertilizer value is then performed.

Sample lab test results			Weight assuming 8.35 lb/gal	Typical fall 1980 retail prices	Calculated value as fertilizer
Nutrient	ppm	%	lb/1000 gal	$/lb	$/1000 gal
N	6000	0.60	50.1	0.258	12.92
P	1100	0.11	9.2	0.249	2.29
K	2200	0.22	18.4	0.135	2.48
					$17.69

Estimating Potential Value of Effluent as Fertilizer

rates will also vary with weather, soil type, and application method.

The previously described Kaplan Industries facility in Florida has demonstrated the possibility of using effluent to reclaim marginal farm lands. The installation is located on an abandoned phosphate mine with "ruined" soil that supports little or no plant life. Land application of digester effluent, however, has produced very promising reclamation results.

Digester Effluent as Feed Replacement

Dried poultry waste has been used for years by some feedlot operators as a replacement for a small fraction of feed for beef cattle. Federal Drug Administration (FDA) objections to this practice motivated the longstanding practice of shipping this material interstate as "fertilizer" rather than as feed. Research failed to confirm any adverse

Land reclamation by Kaplan Industries at Bartow, FL. The area in the foreground is untreated, whereas the land in the background has received about 180 tons of digester effluent per acre. Vegetative response has been very encouraging. Photo: Cal Recovery Systems, Inc.

At the Lamar, Colo., biogas test site, effluent from the digester is centrifuged and the liquid portion is saved for fertilizer. The solids are sundried and stirred with the power rake as pictured in the photo on the left, or air dried in a grain dryer; they also can be fed wet silage. As participants in controlled feed trials, the cattle, in the photo on the right, are eating a treatment ration which has 10% digester solids replacing alfalfa. Photos: Biogas of Colorado

health consequences of refeed, however, so after a period of "looking the other way" FDA announced in February 1980 that it was rescinding its objections to the feeding of wastes to beef cattle. Regulation is now left to the states, except that FDA will continue to enforce for adulteration in interstate shipments. Although some states still recognize only poultry waste, an increasing number are adopting or considering regulations patterned after the 1980 model recommended by the Association of American Feed Control Officials which covers digester effluent.

Research on the nutritional effects and economics of feeding digester sludge to beef cattle is underway at several locations. Work at the U.S. Meat Animal Research Center at Clay Center, Neb., has shown that effluent sludge has about double the amino acid content of fresh manure and makes a good protein supplement. The emphasis in these tests is on the partial replacement of soy protein supplement, much enhancing the overall economics of biogas production for feedlot operations. The Calorific plant at the 100,000-head feedlot in Guyman, Okla., is constructing the first large-scale refeed production operation in the country, and other, smaller facilities are in the planning stages in various locations.

Tests at the Imperial Valley Biogas Project feedlot have shown that centrifuged and sun-dried effluent feedcake can be directly substituted for medium-quality alfalfa hay up to a limited fraction of ration without affecting normal beef carcass weight gain. Feedcake was substituted in feed trials at 6% and 12% of a high-energy finishing ration composed principally of rolled barley. Results led to the final determination that 9% feedcake was comparable in energy value to 9% alfalfa. One phase of current research is aimed at reducing the ash level in effluent to derive a feedcake with higher nutritive value. Also, centrifuge efficiency is being raised from the customary 60% by using a polymer flocculant with the expectation of increasing the protein level of the feedcake. Tests are underway comparing raw manure with cake as a feed material. Experimental results at Imperial Valley suggest that a closed-loop, feed-refeed system makes economic sense for a medium-scale feeder operation. More information on the Imperial Valley feed tests can be found in Dr. Michael Prokop's article on manure fermentation residues, listed in the reference section of this booklet.

Very favorable results from feeding anaerobic residues have also been reported from research conducted at the Lamar-USDA biogas test site at Lamar, Colo. Digester residue was successfully substituted in feed trials for alfalfa pellets and part of the hay ration, with compensatory adjustment in the supplement. Also, recent work has shown that centrifuged effluent can be successfully mixed at a 5% dry-basis proportion with silage for same-day feeding. The acidic silage has a neutralizing effect on the slightly alkaline residue, resulting in a sweet-smelling mixture which cattle reportedly seem to like. Details are given in the Four Corners Regional Commission report listed in the reference section.

Refeeding is a rapidly growing area of interest. It is especially important to beef cattle feeders considering biogas production because the value of effluent can dramatically affect the overall economic feasibility of a digester installation. For many operations the feed value of digester effluent may actually be greater than the value of biogas produced.

Costs and Savings

Even for the enthusiastic farmer inspired by prospects of energy self-reliance, the critical questions concerning possible investment in a biogas system are: 'What will it cost?" and "Will it pay?" The following items should be considered in an investment analysis, though not all of them can safely be assigned dollar figures.

Item	Cash Flow
Capital costs	Site-dependent. Cost of the digester system itself can be estimated and manufacturers and consulting firms are now offering quotations. Discussion follows.
Operation and maintenance costs	Variable but not high. Farmer must decide how to charge for extra time necessary to operate and maintain system.
Energy cost savings	Site-dependent but can be estimated. A procedure is suggested below.
Effluent value	Depends upon present manure handling system and proposed use of effluent. May be significant but no dollar estimates are offered here.
Environmental enhancement	Depends upon present situation and needs. Value of odor control or stream pollution abatement may be high in some cases, but no estimates are offered here.

Capital Costs

Unfortunately, the often experimental nature of most U.S. biogas installations to date has limited the availability of verifiable capital cost and energy savings information. The object of this section is to provide a frame of reference for making cost or cash flow projections and for comparing system proposals by consultants or manufacturers.

It is impossible to estimate with precision how much a digester system should cost given only the type and number of animals. As with an investment in a new milking parlor, farrowing house, or hatchery, the system specifications and costs will be a function not only of the farmer's needs but also of the farmer's desires. Even equipment bare minimums will vary with each application, depending on such factors as adaptability of the existing waste management system, operating layout, and intended use for the biogas.

When estimating equipment requirements and costs, it is important to think of a biogas installation as a total system rather than to deal with components separately. This improves the overall estimate, provides a systematic basis for comparing alternatives, and reduces chances for unpleasant surprises that sometimes occur when careless assumptions are made or required system components are overlooked. A worksheet (see Appendix A) can be used as a checklist during system planning and to assure an apples for apples comparison when evaluating alternate system proposals. (For completed sample worksheets, see Appendix B).

A growing number of competent consultants and manufacturers are prepared to offer planning assistance and capital cost estimates for systems meeting individual needs and specifications. It is a good idea to get more than one estimate and to check the credentials of any potential contractors. In addition to the many knowledgeable people available to assist in the various planning and construction phases—from feasibility study to system startup—there are others ranging from the conscientious but inexperienced to the outright incompetent.

The rapidly expanding nature of the budding biogas industry suggests caution in a dynamic area where cost estimation is a risky business. It may not be long, though, before it will be possible to select components and estimate in-place system costs from catalogues, allowing professionals to concentrate on planning and design, construction, and start-up services. Also, as more owner-built digesters are completed, with many based on Cornell's plug flow design and excavation-construction recommendations, improved cost information on this type installation should become available. Cornell engineers currently estimate the cost of soil-supported, membrane-covered, plug flow digester-gas storage systems at less than one-half the cost of equivalent rigid tank installations with separate storage. There are many fixed cost items both system configurations might share, however, depending upon intended gas and effluent usage, so total comparable system costs will vary less significantly. Also, construction, labor, and long-term maintenance should be considered in cost comparisons.

An increasing number of states are offering tax credits for investment in conservation measures and renewable energy systems. Respective state energy offices have information on programs

Savings from use of biogas are in proportion to the cost of fuel avoided. Biogas would be worth more to a farmer replacing propane or fuel oil than to one replacing natural gas. In the extreme, it would likely be worth nothing to an operator with a private gas well behind the barn. The table below presents dollar values of various fuels and electricity on a Btu basis.

Fuel	Assumed unit price	Assumed Btu/unit	Cost per million Btu
Natural gas	$4.50/1000ft³	1,000,000	$ 4.50
Wood	100/cord	15,000,000	6.67
Fuel oil	1.25/gal	140,000	8.92
Propane	0.90/gal	91,500	9.84
Gasoline	1.40/gal	125,000	11.20
Electricity	0.05/kWh	3,412	14.65
Ethanol	1.90/gal	80,000	23.75

Estimating Rates of Savings from Fuel Replaced

which apply to biogas production. At the federal level, in addition to the regular 10% investment tax credit, the 1980 Windfall Profits Tax Law extended availability of the 10% business energy credit for biomass energy systems. This credit applies to that portion of digester system investment which can be shown to be specifically for the purpose of energy production. Complete information can be obtained from any local office of the Internal Revenue Service.

Energy Cost Savings

Use of biogas to displace purchased fuel provides only one of several potential cost savings from investment in an anaerobic digestion system. Refeed savings may in some applications exceed energy cost savings, but only energy is considered here due to lack of definitive information on refeed values. The basic approach is to approximate the annual energy recoverable from biogas produced, in Btu, and then to estimate how much purchased fuel or electricity this could replace.

The worksheet presented in Appendix C is intended as a crude tool for organizing and comparing data on energy usage with projected biogas energy yields. A farmer wanting to project possible cost savings will be interested in completing the worksheet, but any conclusions should be drawn with great care. (For a sample worksheet, see Appendix D.) A rescheduling of fuel uses may be necessary to balance production and consumption rates in order to take full advantage of "on paper" savings. Limited gas storage capacity will not allow poor planning or careless usage practices. The worksheet can be modified to suit individual needs.

A meaningful economic analysis would require estimates of operation and maintenance costs as well as an escalation rate in energy savings. Since energy costs are increasing faster than the general inflation rate, the first year savings reflected in completion of the worksheet represents the least savings to be expected over the life cycle of the system.

A simple payback analysis can be made by sequentially subtracting projected annual savings from the capital cost estimate to see how many years are required to "pay off" the investment. This is not the best procedure, however. A thorough cash flow analysis is recommended to adequately account for investment and depreciation tax credits, energy cost escalation rates, equipment life, and the time value of money.

At least two companies now offer economic analyses based on information provided by the farmer. Some of the firms listed in the Information Sources Section beginning on page 27 have computer programs that provide rapid and relatively low-cost assessments for all types of farming operations. Computer output includes cash flow projections, rate of return estimates, and other information helpful in bracketing economic feasibility or in reviewing financial needs with lending institutions. Other consultants, schools, and extension offices may also be able to provide a similar service. It is best to give as complete information as possible to a tax accountant or bank loan officer, who should be able to provide guidance on overall system economics and financing alternatives.

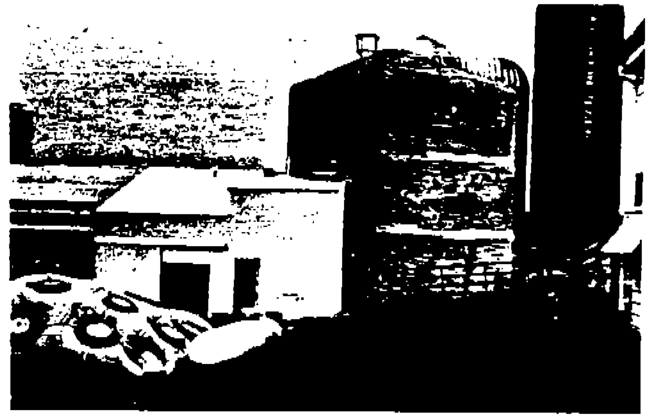
Where to from Here?

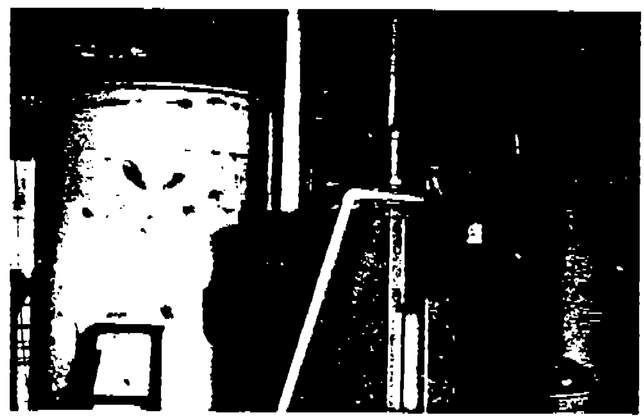
Biogas production is not for every livestock or poultry farmer. Most farmers can profit, though, by studying opportunities to conserve if not to actually produce energy. Anyone seriously interested in investing in an anaerobic digester should first sit back and consider his or her entire farm operation in perspective. It may be important to sharpen the way the farm is viewed—and conducted—as an integrated system. Some operators may even wish to reconsider the focus or scope of their farm activities. An ethanol still, greenhouse, or ice cream plant may suddenly make sense, for example. If biogas is to play a role in a farm's future, a well planned and imaginative system can help to maximize the benefits.

Every system should be custom-crafted to meet particular needs and individual preferences and to take best advantage of current farm operations and practices. A variety of plans are available for home-built systems. It may be satisfying and less costly to plan and build one's own system, especially for small operations, but it would be foolish if not dangerous to proceed without first talking with people who have had firsthand experience with system design and installation. Also, the advantages of leaving some of the risks and responsibilities to a consultant-installer or manufacturer should not be overlooked. Consultation with an extension service agent, agricultural engineer, or consulting firm familiar with biogas facility design and operation is advised.

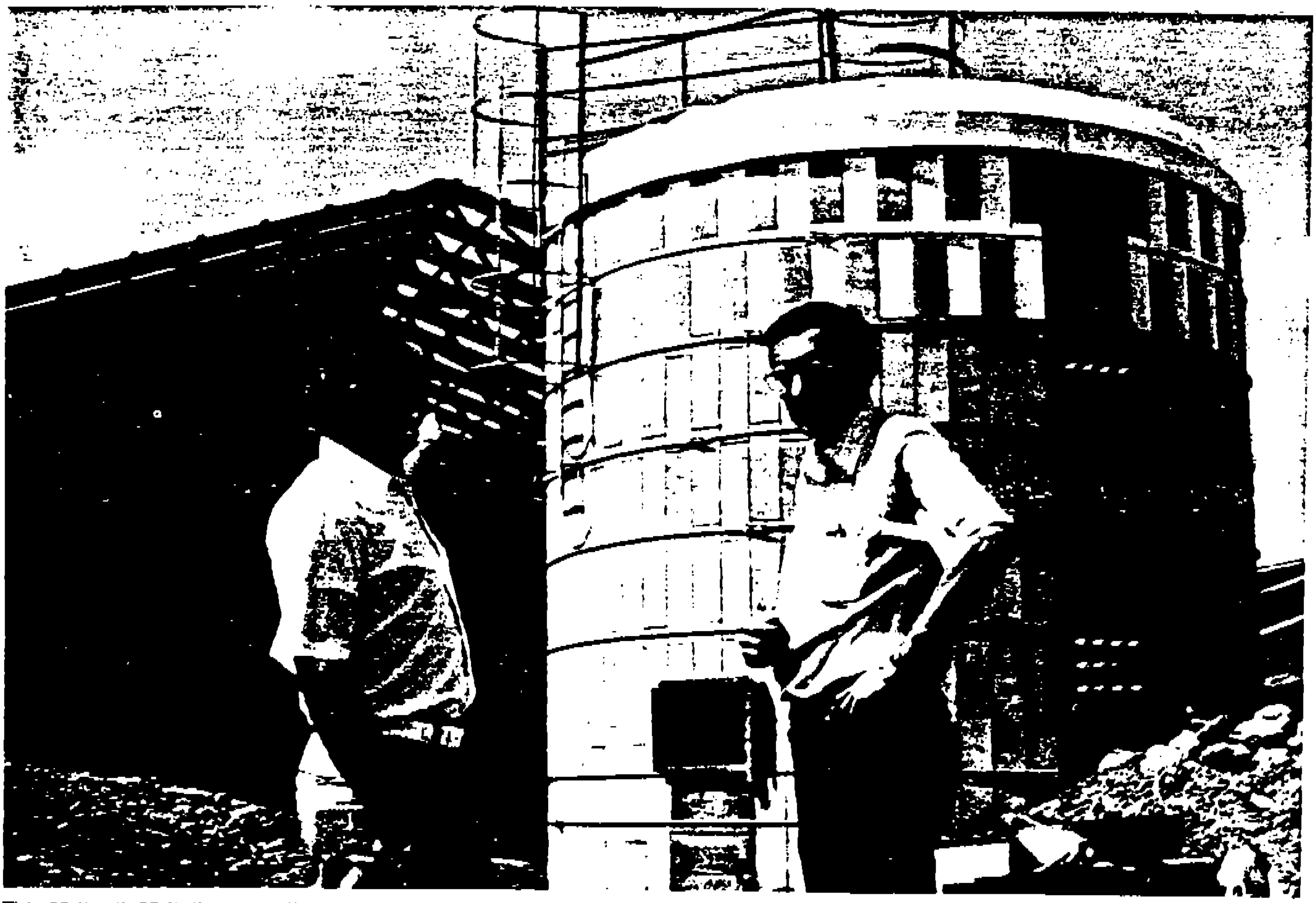
Even with the best advice few farmers would want to consider investment without first actually seeing a biogas system in operation. A visit to a state agricultural college demonstration facility or other installation will pay dividends. The digester, manure and gas handling systems, and overall installation should be studied for design ideas and maintenance and safety features found by experience to be desirable. Also, personnel at these sites are often able to offer helpful hints on how to best meet particular needs.

The Agway Farm Research Center in Fabuis, N.Y. (south of Syracuse), is installing a digester system to accept manure from 180 equivalent mature or lactating dairy cows. The system includes a 20-ft-tall, 20-ft-diameter silo digester based on a Pennsylvania State University design and is integrated with a complete, semisolid manure storage and handling system. Plans call for using the biogas to generate electricity and capturing engine heat for drying effluent to be used as bedding and refeed for replacement heifers. The system will be operational in early





An unusually sophisticated, totally automated biogas system was installed by Biogas of Colorado in the fall of 1980 on the Evan Leeter Farm in Carlinville, Ill. The top photo shows a 150,000 gal. digester tank which accomodates waste from 1000 confined beef cattle. This is an A.O. Smith Aquastore porcelain-coated steel structure, coated with polyurethane foam insulation. In front of the equipment building at the left is a low-pressure biogas storage tank. The center photo shows a hydrogen sulfide scrubber at the left, a boiler which supplies process heat, and a master control electrical panel. The bottom photo shows a 30,000 gal. storage tank which accomodates one and a half day's biogas production at 250psi. The lagoon provides storage for the liquid effluent from the digester until the fields are ready to use it as fertilizer.



This 20-ft tall, 20-ft diameter silo digester at Agway Farm Research Center in Fabius, New York, accepts manure from 180 equivalent mature or lactating dairy cows. Photo: Agway

1981. Visitors to the Research Center will also have the opportunity to learn about a variety of other energy saving equipment, practices, and research projects.

Visitors to southwestern Virginia have an opportunity to see a new small dairy digester system installed during Fall 1980. The system is on the 100-head Otter Run Dairy in Bedford, by Anaerobic Energy Systems of Bartow, Fla., and is open for public tours.

Traveling road shows are providing opportunities for public review of biogas technology. The Bio-Energy Council and DOE funded Bio-Gas of Colorado to build and operate a mobile unit, which toured the South and East in May and June 1980. The digester, mounted on a 16-ft trailer, is pulled by a van that can run on either methane or gasoline. A solar collector provides heat to the system, which is fed animal wastes daily when on display. Tour stops included schools, fairs, technical conferences, farmer's co-op meetings, and local special events. Lack of funding has temporarily precluded further travel, but Bio-Gas of Colorado is offering seminars and workshops in Colorado and host states as part of an ongoing educational program.

The California Energy Commission supported preparation of a trailer-mounted digester by the University of California at Davis. This display includes a laboratory facility where samples of influent and effluent can be analyzed. It was unveiled at the Bank of America Livestock-Agricultural Symposium in Fresno at the end of May and is scheduled to tour four different sites over a one-year period. Included in the tour schedule are a dairy farm, a poultry farm, a swine operation, and a tomato cannery, where biogas production from food wastes will be demonstrated. The primary purpose of the tour is to encourage farmers to apply for no-interest loans for the installation of permanent facilities on farms in California. The Imperial Valley Bio-Gas Project is also available for tours. To make arrangements, contact Pacific Gas and Electric Co. in San Francisco.

Pennsylvanians will get the first look at a mobile digester funded by DOE's Appropriate Technology Small Grant Program for Region III. This is a 6000-gal unit, with assorted paraphernalia, mounted on a 40-ft semitrailer. The DOE grantee, Jerome K. McKeown of Lancaster, is scheduled to introduce the display at the State Fair in Harrisburg in January 1982. Visits will be made thereafter to universities, county fairs, large farms, and feedlots in cooperation with a program supported by the Governor's Energy Council, the State Agriculture Department, and the State Extension Office. After 1981, the demonstration will travel to other states in Region III.

DOE is sponsoring 11 demonstration projects, some of which will not be completed until 1982. These projects involve integrated farm energy systems and will demonstrate the operation of digesters in conjunction with other technologies, such as ethanol production and solar grain drying. These are described in the DOE program summary document listed in the reference section under Power Production. Also, DOE is sponsoring a touring Integrated Farm Energy Systems Exhibit. The exhibit displays information on various energy production and conservation technologies and techniques designed to help farmers achieve relative energy self-sufficiency. Information on the availability of the exhibit can be obtained from DOE's Office of Consumer Affairs (see the Information Sources Section).

Dozens of other installations across the country are in various stages of completion. Information on the status and location of these installations should be available from local county extension service offices and state energy agencies. The four Regional Solar Energy Centers also offer information on demonstration sites and limited guidance on project planning.

Information Sources

A partial listing of firms and agencies experienced with biogas applications follows. These may be helpful to farmers interested in obtaining further information or considering investment in digester systems.

The list of resource people and organizations is provided for your information. Neither DOE nor SERI recommends or vouches for these sources.

Ag Ferm Corp. P.O. Box 55604 Indianapolis, IN 46205 317/873-6003 Fred Lindsey	Provides consulting, design, and turnkey installation services for both biogas and ethanol plants. Experienced in all types of systems including anaerobic filter digesters.
Agricultural and Food Processing Branch Office of Industrial Programs U.S. Department of Energy 1000 Independence Ave. Washington, DC 20585 202/252-2075 Larry Kelso Wanda Porterfield	Provides information on demonstration programs involving alternate and integrated farm energy systems. Has managerial responsibility for the DOE-sponsored integrated farm energy system demonstration program.
Agricultural Energy Resource Recovery, Inc. 124 Arch St. Lancaster, PA 17603 717/299-6215 Jerome McKeown	Anaerobic digestion consulting, design, manufacturing, and installation services. Lectures and workshops also provided through area schools and colleges.
Anaerobic Energy Systems, Inc. 170 N. Florida Ave. P.O. Box 1477 Bartow, FL 33830 813/533-4161 Elizabeth Coppinger	Provides consulting, design, and construction of anaerobic digestion systems. Also offers seminars on the use of digestion in agricultural production and processing operations. Services ranging from feasibility studies to turnkey systems are offered.
Associated Engineers and Environmental Scientists 1003 Tripnammer Rd. Ithaca, NY 18450 607/257-7176 Ray Loehr or 118 Euclid St., N.W. Washington, DC 20009 202/234-9595 Mark Moser	Design, construction supervision, and startup of biogas systems. Also, consulting services in the areas of animal facility waste management and production of animal feed products from organic residues.
Bio-Gas of Colorado, Inc. 5611 Kendall Ct. Arvada, CO 80002 303/422-4354 Fred Varani Susan Schellenbach John Downs	Consulting, research, and design of anaerobic digestion systems and facilities. Extensive experience in designing, building, and operating pilot plants farm systems and utility-sized facilities and evaluating alternative uses for biogas and digester effluent. Now offering cost estimates and turnkey installations for all size farms. Educational services available, tailored to group needs. Seminars offered on a regular basis.
California Energy Commission 1111 Howe Ave. Sacramento, CA 95825 916/920-6033 Rich Lang Ralph Chandler	Provides general and technical information to California residents about anaerobic digestion and other energy technologies.

Cal Recovery Systems, Inc. 160 Broadway, Suite 200 Richmond, CA 94804 415/232-3066 Luis Diaz Clarence Golueke	Feasibility and design of systems for recovering energy and materials from residues. Emphasis is placed upon integrated farming and using various processes to optimize resource recovery.
Ecotope Group 2332 E. Madison Seattle, WA 98112 206/322-3753 David Baylon	Provides information and consulting on anaerobic digestion. Built and operated a digester on a 200-head dairy for the State of Washington. Speakers available.
Energy Harvest, Inc. Suite 602 1735 I St., N.W. Washington, DC 20006 202/659-3030 Bud Nagelvoort	Subsidiary of Sheaffer & Roland, Inc. Provides environmental consulting and engineering services in the harvesting of energy from solar and waste sources. Experienced in design and turnkey installation of digester systems. Other offices in Chicago and Denver.
Energy Management Utilization Division Rural Electrification Administration USDA Washington, DC 20250 202/447-5723 Ken Alexander	Concerned with techniques of conservation, alternative energy, and electrical load management on the farm. Provides information to rural electric cooperatives and others on questions concerning interconnections between utilities and small power producers wishing to sell electricity.
I. E. Associates 3704 11th Ave., South Minneapolis, MN 55407 612/825-9451 Tom Abeles	Offers computerized energy and economic analyses for farms and designs of integrated energy systems including solar, alcohol, and methane.
National Center for Appropriate Technology P.O. Box 3838 Butte, MT 59701 406/494-4572 Sue Raker Bob Moody	Provides information and inexpensive publications on biogas and ethanol production and other solar technologies, with an emphasis on bringing integrated energy systems within reach of the small or low-income family farm. Research and development assistance, demonstration projects, and small grants available on a limited basis.
New York State Energy Office Agency Building 2 Rockefeller Plaza Albany, NY 12223 518/474-5874 Ellen Bogardus	Provides information to New York residents on anaerobic digestion and other technologies for small-scale energy or power production.
OASIS 2000 Box 1, Admin. Bldg. University Dr. Rice Lake, WI 54868 715/234-8176 David Ellsworth	Provides technical assistance including feasibility studies for anaerobic digestion. Also can provide speakers and lead workshops for anaerobic digestion and other solar-related technologies.
Office of Consumer Affairs U.S. Department of Energy Washington, DC 20585 202/252-5141 Ron Highnote	Information under development on pioneering education programs and consumer protection issues involving community-based energy programs. Posters and information available on the DOE traveling Integrated Farm Energy System Exhibit.
Perennial Energy, Inc. P. O. Box 15 Dora, MO 65637 417/261-2547 Ted Landers David Jessee	Design and installation of package digester and integrated farm and industrial energy systems. Establishing a network of dealers for local service. Distributor for Marathon induction motors for use with power generation systems.
Solar Energy Research Institute 1617 Cole Blvd. Golden, CO 80401 303/231-1000	Manages and conducts research and development to promote the application of solar energy technologies.
Southern Agricultural Energy Center Coastal Plain Experiment Station USDA Tifton, GA 31794 912/386-3585 Dr. James Butler	Responsible for a variety of regional solar energy programs. In addition to biomass development work at Tifton, the Center coordinates wind energy programs at Ames, Ia., and Brushland, Tx., and biogas research at Columbia, Mo. General information on the various programs is available directly, while requests for specific, technical information are referred to the appropriate research staffs.

Systems Technology Corporation 245 N. Valley Rd. Xenia, OH 45385 513/372-8077 Joseph Swartzbaugh	Has built a full-scale, 100,000 gal digester for municipal solid waste. Also has done some work with local farmers on the design of anaerobic digesters.
U.S. Dept. of Agriculture/FmHA 14th and Independence Ave. Washington, DC 20585 202/447-7595 David Salazar Tom Bergum	Administers a loan program to help finance the construction of anaerobic digesters on farms. Will provide information and technical assistance for farmers.

Financial Assistance

A number of programs now in operation may assist a farmer in financing a digester system.

USDA Farmer's Home Administration (FmHA)

FmHA offers three loan programs to farmers who cannot obtain bank financing for the construction of a digester system. The Farm Operations Loan Program has a limit of $100,000. The term is seven years but can be renewed. The Farm Ownership Loan has an upper limit of $200,000 and a term of 30 years. Both loans are available at the standard FmHA interest rate. Also, 90% guaranteed loans of larger amounts are available through the Business and Industries Program. This program is attractive to banks because the loans do not affect their reserve requirements.

In addition, FmHA is responsible for administering a promising new financial assistance program resulting from the Biomass Energy and Alcohol Fuels Act of 1980. The aim of this program is to reduce the nation's dependence on petroleum imports by providing direct assistance to farmers and others for the construction of biomass energy projects. Both insured loans of up to $1 million and 90% guaranteed loans are available for terms of up to 30 years. Details and application forms can be found in Part XII of the October 30, 1980 *Federal Register*. Some state energy offices are offering help to farmers interested in applying for assistance under this program. For more information on this and other loan opportunities available through FmHA, contact the FmHA office in your state.

The Department of Energy's Appropriate Technology Small Grants Program

This program annually makes grants of up to $50,000 to support energy-related appropriate technologies, such as anaerobic digestion. These grants are for concept development, development projects, and demonstration projects. DOE's Appropriate Technology Small Grants may be made to individuals, local nonprofit organizations, state or interstate agencies, local units of government, Indian tribes and nations, or small businesses. Average grant size is $12,000. Program information and grant applications are available through regional DOE offices.

Small Business Administration (SBA)

The Federal Water Pollution Control Act (FWPCA) authorizes the SBA to make loans to farms that must upgrade manure handling systems to meet water pollution control requirements. If the business is likely to suffer substantial economic injury without assistance, these loans can be made. Only the equipment that is necessary and adequate to comply with the requirements of the FWPCA is eligible. An entire digestion system would not be eligible, but the upgraded system could be designed to incorporate a digester. The SBA can guarantee a bank loan or make a direct loan of up to $500,000 at the standard interest rate. The maximum term for the loan is 30 years. For more information, contact a regional SBA Office.

State Programs

Several states are offering tax incentive, construction loan, and other assistance programs for businesses and individuals aspiring to produce their own energy. In California, for example, the State Agricultural and Forest Residue Utilization Act of 1979 established a $10 million fund for the support of biomass energy development. The state is offering interest-free construction loans for various kinds of demonstration projects. Loans for several biogas installations are expected to be approved beginning in the fall of 1980. Details on this and other programs can be obtained from the respective state energy offices.

Recommended Reports, Papers, and Books

Digesters and Biogas Production in General

Ashare, E.; Buivid, M.; Wilson, E. of Dynatech R/D Company. *Feasibility Study for Anaerobic Digestion of Agricultural Crop Residues.* SERI/TR-8157-1. Golden, CO: Solar Energy Research Institute. Available from: National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Microfiche $3.00, Printed copy $10.00.

Bio-Gas of Colorado, Inc. Papers on digester design, refeed, algae growth, and various related topics. Publications list available from: Bio-Gas of Colorado, Inc., 5611 Kendall Ct., Arvada, CO 80002.

Biomass Energy Institute, Inc. 1978. *Biogas Production from Animal Manure.* Available from: Biomass Energy Institute, Inc., 204 Cambridge St., Winnipeg, Manitoba. Free while supplies last.

Cobb, Wayne. 1978. *Methane from Manure: A Survey of the Technology of Anaerobic Digestion and Discussion of its Applicability to Maine Agriculture.* Maine Office of Energy Resources, Dept. of Environmental Protection, Augusta, ME. Free.

Converse, J. C. et al. 1977. "Performance of a Large Size Anaerobic Digester for Poultry Manure." *Transactions.* Paper No. 77-0451. Available from: American Society of Agricultural Engineers, P.O. Box 410, St. Joseph, MO 49085. $1.50.

Coppinger, Elizabeth et al. 1979 (Dec.). *Report on the Design and Operation of a Full-Scale Anaerobic Dairy Manure Digester.* Available from: Ecotope Group, 2332 E. Madison, Seattle, WA 98112. $10.00. Photocopy available from: National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161. Cite: SERI/TR-312-471. $6.00.

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Appendix A

Capital Cost Estimating Worksheet

Capital Cost Estimating Worksheet

Estimate For:

Farmer or Farm Name ______________________

Address ______________________

____

Phone ______________________

Date ______________________

Prepared By: Self ____ Consultant-Contractor ____

Name ______________________

Firm Name ______________________

Address ______________________

____

Phone ______________________

Summary Description of Proposed System, Equipment, and Services

Animal Type(s): ______________________

Approximate Number(s) in Confinement: ______________________

Confinement Facilities Description: ______________________

Existing Manure Collection and Disposal System: ______________________

Modifications Required, and by Whom: ______________________

Intended Use for Biogas: ______________________

Summary of Proposal: ______________________

____

____

____

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Manure management system modifications					
Influent delivery system conveyors, scrappers, troughs, etc.					
Manure pump					
Pit pump					
Effluent handling troughs, ditching piping, pumping, storage tank, lagoon					
Other					
Subtotal					
Mixing tank or pit with mix and transfer equipment					
Digester and accessories					
Site preparation					
Digester tank					
Digester bag					
Digester concrete or blocks					
Plastic or rubber bag or cover					
Insulation					
Mixer or stirrer					
Recirculation pump					
Sludge pump					
Other					
Heating system water heater or boiler					
expansion tank					
circulation pump					
heat exchanger					
piping					
Subtotal					

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Effluent handling equipment					
Gas storage and handling					
storage container(s)					
compressor					
gas treatment system					
piping and winter protection					
traps, valves, gauges					
waste gas flare					
gas meter					
safety equipment					
appliance conversion					
backup supply connections					
Subtotal					
Control system and facilities					
control panel					
wiring					
building					
misc.					
Subtotal					
Optional power generation equipment					
engine-generator set					
synchronizing equipment					
wiring and controls					
backup supply and equipment					
heat recovery equipment					
soundproofed enclosure					
Subtotal					

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Optional effluent use equipment for refeed, bedding, etc.					
Other necessary facilities, equipment, or modifications					
Other optional buildings, facilities, equipment, or modifications					
Site preparation					
Construction supervision, mechanical checkout, and site cleanup					
System inspection, biological startup, and initial monitoring					
Operator instruction and training					
TOTAL capital cost for system installed and operating					
Subtotal					
TOTAL					

Appendix B

Completed Sample Capital Cost Estimating Worksheet(s)

Three firms responded to requests for quotations on representative biogas systems. Bio-Gas of Colorado submitted a capital cost estimate for a 1000-head feedlot. Energy Harvest submitted information for a 650-cow dairy, and Perennial Energy provided costs for a 1500-hog farrow-to-finish operation.

The three firms had a limited time to prepare the cost information. Bio-Gas of Colorado noted that an actual proposal would contain more detail, and Energy Harvest was able only to provide an overview of their dairy system proposal. Perennial Energy submitted supplementary energy production and savings estimates, and this information has been included with their proposal.

The systems described are very different from one another and are not intended for direct comparison. This information is intended solely as a frame of reference for farmers interested in estimating their own system needs or costs or in comparing alternate proposals prepared specifically for their operations.

Capital Cost Estimating Worksheet

Estimate For:

Farmer or Farm Name John Doe

Address Unspecified

Phone

Date August 22, 1980

Prepared By: Self ____ Consultant-Contractor X

Name John Downs

Firm Name Bio-Gas of Colorado

Address 5611 Kendall Ct.

Arvada, Colorado 65637

Phone 303-422-4354

Summary Description of Proposed System, Equipment, and Services

Animal Type(s): Beef cattle

Approximate Number(s) in Confinement: 1000

Confinement Facilities Description: Environmental feedlot

Existing Manure Collection and Disposal System: Slated floors

Modifications Required, and by Whom: None

Intended Use for Biogas: Residential space and water heating, alcohol still heating

Summary of Proposal: 150,000-gal bolted-steel digester tank with heating and mixing equipment. Manure slurry mix and feed system. Gas compression and storage system including 20,000-gal low-pressure storage bag and 30,000-gal, 250-psi steel storage tank. Completely automated control system. Mechanical and biological startup services included. Under assumed midwest climatic conditions a year-round average biogas production equivalent to 240 gal of propane/day is anticipated.

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Manure management system modifications					
Influent delivery system conveyors, scrappers, troughs, etc.	Piping and valves				
Manure pump					
Pit pump	Submersible pump with hoist				
Effluent handling troughs ditching piping, pumping, storage tank, lagoon					
Other	Pipes, valves, and controls				
Subtotal					
Mixing tank or pit with mix and transfer equipment manure settling pit	1700-ft^3 poured				
Digester and accessories					
Site preparation					
Digester tank	150,000-gal, porcelain-coated, above-ground bolted-steel tank				
Digester bag					
Digester concrete or blocks					
Plastic or rubber bag or cover					
Insulation	4-in. polyurethane spray				
Mixer or stirrer					
Recirculation pump	15-hp centrifugal				
Sludge pump					
Other					
Heating system water heater or boiler	Forced draft, 500,000-Btu steel industrial boiler; 30-gal pressurized bladder tank				
expansion tank					
circulation pump					
heat exchanger	11-ft panel coil cylinder, internally mounted in digester				
piping	Black iron, as required				
Subtotal					

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Effluent handling equipment	Overflow to lagoon				
Gas storage and handling					
storage container(s)	20,000-gal, nylon-reinforced rubber gas bag; 30,000-gal, 240-psig ASME gas storage tank				
compressor	250-psi 2-stage air compressor				
gas treatment system	H_2S removal				
piping and winter protection	Black iron piping with insulation				
traps, valves, gauges	Condensation traps, relief valves, pressure gauge				
waste gas flare	Automatic				
gas meter					
safety equipment	Flare alarm				
appliance conversion	Furnace dual fuel conversion				
backup supply connections					
Subtotal					
Control system and facilities					
control panel	Complete, automated wiring control module				
wiring					
building					
misc.					
Subtotal					
Optional power generation equipment					
engine-generator set					
synchronizing equipment					
wiring and controls					
backup supply and equipment					
heat recovery equipment					
soundproofed enclosure					
Subtotal					

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Optional effluent use equipment for refeed, bedding, etc.					
Other necessary facilities, equipment, or modifications					
Other optional buildings, facilities, equipment, or modifications					
Site preparation					
Construction supervision, mechanical checkout, and site cleanup	Complete—no customer labor required				
System inspection, biological startup and initial monitoring	Laboratory testing of manure, biogas, and effluent				
Operator instruction and training	Operation handbook preparation and instruction; On-site training program for operation, monitoring, and maintenance				
TOTAL capital cost for system installed and operating					
TOTAL					$181,000

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August 13, 1980

Mr. David G. Palmer
Solar Energy Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

Dear Dave:

After assigning staff people to prepare the information for your worksheets so that we could get this promised material to you, I find that the format simply does not fit our circumstances. Consequently, I have prepared a brief analysis of a Michigan Dairy Farm system in a form which hopefully can be of use.

The Baum Dairy in Michigan milks 650 cows. It pays about 6.5¢ per kilowatt hour for electricity with total electricity cost almost $30,000 this year. It has odor problems from the lagoons where manure scraped daily from dairy barns and feed areas is now stored before being irrigated or spread on cropland.

Energy Harvest, Inc., of Chicago, Illinois, has designed a plug flow anaerobic digestion system for this farm. It consists of a concrete mixing tank with a capacity of 10,000 gallons into which fresh manure will be scraped, a Flygt manure pump to homogenize the material as it pumps it to the digester tank, the concrete digester itself with a capacity of 180,000 gallons and 18 days retention time, a 30 mil. hypalon bag covering the digester to collect biogas, a pole barn built over the digester, a 75 Kw dual fuel engine generator set to convert the biogas into electricity, and a building housing the generator equipment.

Additional equipment includes insulation to retain heat in the digester, heat exchange pipes in the digester to heat the manure with hot water from the cooling system of the engine-generator, a pump to circulate water in the heat exchange system, a Rootes blower to increase gas pressure, a gas meter to record gas consumption, a manometer to prevent overfilling of the gas bag, and the electrical wiring and switching equipment to provide power to the farm.

Suite 602. 1735 I Street, NW Washington, DC 20006 (202) 659-3030

The turn key cost of this system is $150,000 before tax credits of 20%. Baum Dairy also intends to purchase a Surge TRU manure solids separator at about $13,000 for production of bedding material from the digested manure.

Biogas generation from the digester will amount to about 27,000 cubic feet per day. Burned at a 90-10 ratio with diesel fuel at 20% efficiency the system will produce about 386,000 Kwh of electricity per year. At 6.5¢ per Kwh this power is worth about $25,000 annually. Assuming diesel fuel at 90¢ per gallon, the value of the diesel is about $4,400. With operating costs of the system at about 2.5% of gross construction costs ($3,750), the net value of the electricity is about $17,000. Considering inflation in power costs about equal to interest rates over the years, the after tax cost recovery for the system is about 7 years from electricity generation alone.

It is necessary, however, to consider also the value of pollution control for which a dollar value is not determined and the value of bedding to be produced from digested solids. Because the bedding is essentially pathogen free it has substantial value for mastitis reduction.

I will be pleased to fill in any gaps over the phone if it will be helpful.

Sincerely,

ENERGY HARVEST, INC.

Bernard C. Nagelvoort cnl

Bernard C. Nagelvoort
President

BCN/cnl

Capital Cost Estimating Worksheet

Estimate For:

Farmer or Farm Name ______

Address ______

Anywhere, Arkansas

Phone ______

Date ______

Prepared By: Self ____ Consultant-Contractor X

Name Ted Landers

Firm Name Perennial Energy, Inc.

Address P.O. Box 15

Dora, Missouri 65637

Phone 417-261-2547

Summary Description of Proposed System, Equipment, and Services

Animal Type(s): Hogs

Approximate Number(s) in Confinement: 240 sows, 1500 farrow-to-finish

Confinement Facilities Description: Total confinement, farrow-to-finish, hot water in slab heating

Existing Manure Collection and Disposal System: Gravity "porta-pan" underslats to lagoon

Modifications Required, and by Whom: None

Intended Use for Biogas: Heating hog confinement buildings

Summary of Proposal: An 8000-ft^3 digester with 6000-ft^3 gas storage at 1/4 psi will be placed as a separate building between the hog buildings and lagoon. Expected average output will be 3.2 MBtu/day net usable energy after digester heating. Substituting for propane at $0.65/gal nets: if 100% utilized, $8200 fuel return/year; if 60% utilized, $4900 fuel return/year. Installed system complete and operating: $24,567.00. Supplemental information attached.

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Manure management system modifications					
Influent delivery system conveyors, scrappers, troughs, etc.	Existing gravity "porta-pan" to digestor				n/a
Manure pump					
Pit pump					
Effluent handling troughs ditching piping, pumping, storage tank, lagoon					
Other	Piping				100
Subtotal					
Mixing tank or pit with mix and transfer equipment	n/a				
Digester and accessories					
Site preparation	Surveying				50
	Excavation 750 ft³ (38-ft × 38-ft × 14-ft deep)				950
Digester tank	Gravel 25 yards				200
Digester bag	49 corrugated steel galvanized panels				2100
Digester concrete or blocks					
Plastic or rubber bag or cover	Perennial D8/B-29-14-10 tank and cover with baffles, heat exchanger, and ports				6000
Insulation	4-in. foam in walls, 2-in. under, and 6-in. on top		2940		
Mixer or stirrer	n/a				
Recirculation pump	n/a				
Sludge pump	n/a				
Other	Gravity flow to lagoon				
Heating system water heater or boiler	Loop from hog house heating system (see piping below)				
expansion tank	Perennial expansion tank ET-1				10
circulation pump	2-1/20 hp circulating pump				177
heat exchanger	Built into digester wall—see above				
piping	50-ft insulated pipe to and from digester				200
Subtotal					

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Effluent handling equipment					
Gas storage and handling					
storage container(s)	2-GS/PW perennial storage tanks				1920
compressor					
gas treatment system	H_2S Trap-11 CFM				1440
piping and winter protection	1-in. polyethylene gas pipe and fittings				60
traps, valves, gauges	PEI Condtrap, pressure relief valve and regulators				120
waste gas flare	n/a				
gas meter	2-200 ft^3/min				168
safety equipment					
appliance conversion	Boiler/water heater conversion				800
backup supply connections	n/a				
Subtotal					
Control system and facilities					
control panel	Aqua Stat temp sensor				42
wiring					15
building	8-ft × 8-ft equipment shed				600
misc.					50
Subtotal					
Optional power generation equipment					
engine-generator set	n/a				
synchronizing equipment	n/a				
wiring and controls	n/a				
backup supply and equipment	n/a				
heat recovery equipment	n/a				
soundproofed enclosure	n/a				
Subtotal					

Capital Cost Estimating Worksheet (continued)

Item	Specifications	Material Cost	Equipment Cost	Labor Cost	Total Cost
Optional effluent use equipment for refeed, bedding, etc.	n/a				
Other necessary facilities, equipment, or modifications	36-ft × 36-ft digester housing and gas pressure platform				4040
Other optional buildings, facilities, equipment, or modifications					
Site preparation					
Construction supervision, mechanical checkout, and site cleanup					
System inspection, biological startup and initial monitoring	Total labor for all phases of construction and startup			5880	
Operator instruction and training					
TOTAL capital cost for system installed and operating					
Subtotal				$5880	$18,687
TOTAL					$24,567

Job #1011

Engineering Report

Customer: Arkansas

Digester Sizing

Manure Volume Output at 9.2% solids

$$(500 \text{ finishing pigs}) \left(\frac{0.15 \text{ ft}^3 \text{ av.}}{\text{pig day}} \right) = \frac{75 \text{ ft}^3}{\text{day}}$$

$$(750 \text{ farrow and nursery pigs}) \left(\frac{0.025 \text{ ft}^3 \text{ av.}}{\text{pig day}} \right) = \frac{18.75 \text{ ft}^3}{\text{day}}$$

$$(32 \text{ sows}) \left(\frac{0.43 \text{ ft}^3 \text{ av.}}{\text{pig day}} \right) = \frac{14 \text{ ft}^3}{\text{day}}$$

$$\text{Total } \frac{107.75 \text{ ft}^3}{\text{day}}$$

with 15 day retention

$$\text{Digester size } \left(\frac{107.75 \text{ ft}^3}{\text{day}} \right) 15 = 1616 \text{ ft}^3$$

Nominal size <u>16-ft × 16-ft × 8-ft digester</u>

Digester Energy Production

Digester Gross Energy Production

$$(500 \text{ pigs}) \left(\frac{140 \text{ lb av.}}{\text{pig}} \right) = 70{,}000 \text{ lb}$$

$$(750 \text{ pigs}) \left(\frac{23 \text{ lb av.}}{\text{pig}} \right) = 17{,}250 \text{ lb}$$

$$(32 \text{ sows}) \left(\frac{400 \text{ lb av.}}{\text{sow}} \right) = \underline{12{,}800 \text{ lb}}$$

$$100{,}000 \text{ lb pig av. weight}$$

$$\text{Gross Energy Production} = (100{,}000 \text{ lb pig}) \left(\frac{17.5 \text{ Btu}}{\text{lb pig day}} \right) = 1.75 \frac{\text{MBtu}}{\text{day}}$$

Digester Energy Requirement

$$\text{Skin Loss-Walls } (16 \text{ ft})(8 \text{ ft})(4) \left(\frac{1 \text{ Btu}}{16 \text{ ft}^2 \, {}^\circ\text{F hr}} \right) \left(\frac{24 \text{ hr}}{\text{day}} \right) (35\ {}^\circ\text{F}) = 26{,}800 \frac{\text{Btu}}{\text{day}}$$

$$\text{Floor } (16 \text{ ft})(16 \text{ ft}) \left(\frac{1 \text{ Btu}}{8 \text{ ft}^2 \, {}^\circ\text{F hr}} \right) \left(\frac{24 \text{ hr}}{\text{day}} \right) (35\ {}^\circ\text{F}) = 26{,}800 \frac{\text{Btu}}{\text{day}}$$

$$\text{Top (peak) } (16 \text{ ft})(16 \text{ ft}) \left(\frac{1 \text{ Btu}}{20 \text{ ft}^2 \, {}^\circ\text{F hr}} \right) \left(\frac{24 \text{ hr}}{\text{day}} \right) (90\ {}^\circ\text{F}) = 27{,}644 \frac{\text{Btu}}{\text{day}}$$

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$$\text{Top (average winter)}\left(\frac{1\ \text{Btu}}{20\ \text{ft}^2\ {}^\circ\text{F hr}}\right)\left(\frac{24\ \text{hr}}{\text{day}}\right)(60\ {}^\circ\text{F}) = 18{,}524\ \frac{\text{Btu}}{\text{day}}$$

$$\text{Top (average summer)}\left(\frac{1\ \text{Btu}}{20\ \text{ft}^2\ {}^\circ\text{F hr}}\right)\left(\frac{24\ \text{hr}}{\text{day}}\right)(15\ {}^\circ\text{F}) = 4{,}631\ \frac{\text{Btu}}{\text{day}}$$

$$\text{Winter peak} = 81{,}400\ \frac{\text{Btu}}{\text{day}}$$

$$\text{Winter average} = 72{,}124\ \frac{\text{Btu}}{\text{day}}$$

$$\text{Summer average} = 58{,}231\ \frac{\text{Btu}}{\text{day}}$$

Influent heating

$$\left(\frac{107.75\ \text{ft}^3}{\text{day}}\right)\left(\frac{65\ \text{lb}}{\text{ft}^3}\right)(40\ {}^\circ\text{F}) = 280{,}000\frac{\text{Btu}}{\text{day}}$$

$$\text{Total winter peak} = 361{,}400\ \frac{\text{Btu}}{\text{day}}$$

$$\text{Winter average} = 352{,}124\ \frac{\text{Btu}}{\text{day}}$$

$$\text{Summer average} = 338{,}231\ \frac{\text{Btu}}{\text{day}}$$

Net Monthly Energy Produced in Gallons of Propane =

$$\left(1.75\frac{\text{MBtu}}{\text{day}}\right) - \left(\frac{0.35\ \text{MBtu}}{0.7\ \text{eff. day}}\right)\left(\frac{30.5\ \text{day}}{\text{month}}\right)\left(\frac{1\ \text{gal propane}}{0.0925\ \text{MBtu}}\right)$$

$$= \frac{412\ \text{gal propane}}{\text{month}}$$

	Propane Used 1979 in Farrow and Nursery	Net Digester Energy Production Reducing Propane Bill
Jan.	1000	412
Feb.	1000	412
Mar.	500	412
Apr.	400	400
May	500	412
June	250	250
July	250	250
Aug.	250	250
Sept.	250	250
Oct.	500	412
Nov.	1000	412
Dec.	1000	412
TOTAL	6900 gal	4284 $\frac{\text{gal propane produced per year}}{\text{year}}$

$$(4282 \text{ gal propane}) \left(\frac{\$0.65}{\text{gal}}\right) = \frac{\$2785}{\text{year}} \text{ produced}$$

Solar Collector Energy Production

$$(220 \text{ ft}^2) \left(\frac{1000 \text{ Btu}}{\text{day ft}^2}\right) \left(\frac{30.5 \text{ days}}{\text{month}}\right) (8 \text{ months}) (0.6 \text{ sunshine day}) = \frac{32 \text{ MBtu}}{\text{year}}$$

$$\left(\frac{32 \text{ MBtu}}{\text{year}}\right) \left(\frac{1}{0.7 \text{ furn. eff.}}\right) \left(\frac{\text{gal propane}}{0.0925 \text{ MBtu}}\right) \left(\frac{\$0.65}{\text{gal propane}}\right) = \frac{\$320}{\text{year}} \text{ produced}$$

Energy Demand/Digester Energy Supplied

Month	Average Propane Usage (gal)	Digester Supplied Equivalent Energy MBtu/day	Average Electrical Usage (kWh)	Digester Supplied Equivalent Energy (kWh)	Digester Cannot Supply
Jan	4,500	13.87	46,000	37,657	-8,343
Feb.	2,700	8.32	47,000	53,224	
March	800	5.55	48,000	61,008	
Apr.	1,000	3.08	56,000	67,937	
May	500	1.54	55,000	72,257	
June	500	1.54	55,000	72,257	
July	600	1.85	61,500	71,387	
Aug.	750	2.31	68,500	70,097	
Sept.	780	2.40	77,000	69,845	-7,155
Oct.	750	2.31	61,500	70,097	
Nov.	1,550	4.78	53,500	63,170	
Dec.	4,000	12.33	49,000	41,981	-7,519
	19,430		678,500		-23,000
	+ 5,431 gal/year		-23,000		
	24,861 gal = total replaced by digester		655,500 digester can supply		

(24,861) ($0.60/gal) = $14,918 (655,500 kWh) ($0.042/kWh) = $27,500

$27,500
-14,918
$42,418 reduction in utility bills/year

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Appendix C

Energy Cost Savings Worksheet

Farmer or Farm Name ____________________ Prepared by ____________________

Location ____________________ Date ____________________

Energy Cost Savings Worksheet

Energy Producible per Month	J	F	M	A	M	J	J	A	S	O	N	D	YR
1. Number of animals available (List only those in confinement at specific times of the year).													
2. Biogas producible daily per animal (from Table) × No. of animals = cubic feet gas producible per day													
3. × 600 Btu per cubic foot = Gross Btu producible per day													
4. × 30 days per month = Gross Btu producible per month													
5. − % of gas needed to heat digester (base estimate on weather and digester design) = Net Btu producible per month													
6. *Natural Gas:* Monthly billed cost													
7. ÷ cost per unit: hundred cubic feet, thousand cubic feet, therms (check billing or with utility) ______ = Units used per month													
8. × Btu content per unit (check billing or with utility) ______ = Btu consumed per month													
9. *Propane or Butane:* Monthly billed cost													
10. ÷ cost per unit ______ = Units used per month													
11. × Btu content per unit (91,500 Btu/gal for propane; 102,600 Btu/gal for butane) ______ = Btu consumed per month													
12. *Fuel Oil:* Monthly billed cost													
13. ÷ cost per unit = Units used per month													

Energy Cost Savings Worksheet (concluded)

Energy Producible per Month	J	F	M	A	M	J	J	A	S	O	N	D	YR
14. × Btu content per unit (140,000 Btu/gal for #2 oil) ______ = Btu consumed per month													
15. Sum of lines 8, 11, and 14 = Total Btu consumed per month													
16. Gross Btu producible per month (copy line 4)													
17. ÷ 17,000 Btu per kWh (assuming a 20% conversion efficiency) = net kWh producible per month													
Electricity Consumption per Month													
18. Cost per Month													
19. ÷ cost per kWh ______ = kWh consumed per month													
20. Summary of savings available (must calculate)													

Notes:

1. If direct burning of biogas for heating is anticipated, complete lines 1-15.
2. Compare lines 5 and 15. If the entry for line 5 exceeds the entry for line 15 for any month, the potential first year savings for that month is the sum of lines 6, 9, and 12. If the entry for line 15 exceeds the entry for line 5, compare the entry for line 5 successively with the entries for lines 8, 11, and 14 to determine the extent of partial replacement of existing fuels potentially available. Potential first year savings are proportional to fuel displacement levels.
3. If electricity production only is contemplated, complete lines 1-5 and 16-19. The projected first year savings are proportional to the fraction of line 19 entries represented by line 17 entries, up to the present costs shown in line 18.
4. Usage rates may vary widely over a month's period. If fluctuations exceed capacity of gas storage, actual monthly savings will be limited by the ability to match production and usage rates.

Appendix D

Energy Cost Savings Example

The following example assumes a dairy operation with between 160 and 200 cows confined throughout the year. Since some calves and heifers are included in these numbers, the average animal weight is assumed to be 1000 lb. The fraction of biogas production required for digester heating varies monthly, and estimates are based on the local climate and test data from the digester manufacturer.

Natural gas is not used on this farm, and fuel oil use is limited to vehicles and field equipment. Monthly costs for propane are listed and Btu/month usage rates are calculated as shown.

Comparing lines 11 or 15 with line 5 indicates that biogas producible would easily displace projected propane use each month. If propane replacement is to be the only biogas use, then monthly and annual energy savings are equal to the cost of propane replaced. Since projected biogas production far exceeds levels required for propane replacement, especially in the summer months, additional gas usages should be considered. For example, an alcohol still or power production might be investigated.

Although the savings shown in this example do not reflect potential savings from electricity generation, the relevant data have been provided to allow consideration of this alternative. The numbers in this case clearly show that the potential savings from power production alone are less than for propane replacement alone, so an extra investment in generation does not appear attractive. However, depending on the pattern of kWh use, both electricity generation and propane replacement may make sense.

Considering July as a sample case in which perfect use of generated electricity is assumed, 126,720,000 Btu are available and, if fully used, can generate 7453 kWh, although only 5200 kWh are needed. By simple proportions, 88,412,544 Btu (5200÷7453 x 126,720,000), or about 70% of the total available, could be used to generate 5200 kWh, leaving 38,307,456 Btu unused. If 15% is required for digester heating (depending on the overall contribution from the engine heat exchanger), 32,561,338 Btu would be available as propane replacement. This amounts to about 32/38 of July's demand, for a savings of $214. Under this scenario, total savings (electricity plus propane) for July would be $474; $224 greater than for propane replacement alone. Similar calculations could be made for the remaining months, allowing analysis of the rate of return for an incremental investment in electrical generation equipment.

Farmer or Farm Name Riford's Guernsey

Location 125 Assembly Place, Hardensburg Corners, NY

Prepared by DGP

Date 4/1/81

Energy Cost Savings Worksheet

Energy Producible per Month	J	F	M	A	M	J	J	A	S	O	N	D	YR
1. Number of animals available (List only those in confinement at specific times of the year).	200	200	200	200	180	180	160	160	160	180	200	200	
2. Biogas producible daily per animal (from Table) × No. of animals = cubic feet gas producible per day	8800	8800	8800	8800	7920	7920	7040	7040	7040	7920	8800	8800	
3. × 600 Btu per cubic foot = Gross Btu producible per day'	5.280	5.280	5.280	5.280	4.752	4.752	4.224	4.224	4.224	5.752	5.280	5.280	
4. × 30 days per month = Gross Btu producible per month'	158.400	158 400	158.400	158.400	142.560	126.720	126.720	126.720	126.720	142.560	158.400	158.400	
5. − % of gas needed to heat digester (base estimate on weather and digester design)	45%	50%	40%	30%	25%	20%	15%	10%	15%	25%	55% 102.960	40% 95.040	
= Net Btu producible per month'	87 120	79 200	95.040	110 880	106.920	114 000	107.712	114 048	107 712	106.920	102.960	95.040	
6. *Natural Gas:* Monthly billed cost													
7. ÷ cost per unit: hundred cubic feet, thousand cubic feet, therms (check billing or with utility) ___ = Units used per month													
8. × Btu content per unit (check billing or with utility) ___ = Btu consumed per month													
9. *Propane or Butane:* Monthly billed cost		420	460	420	380	350	300	250	200	240	280	320	380
10. ÷ cost per unit 0.6/gal = Units used per month		700	766	700	630	582	498	415	332	389	465	531	632
11. × Btu content per unit (91,500 Btu/gal for propane; 102,600 Btu/gal for butane) 91,500 = Btu consumed per month		64 050	70.089	64 050	57.828	52.253	45.567	37.972	30.378	36.417	42.547	48 585	57.828
12. *Fuel Oil* Monthly billed cost													
13. ÷ cost per unit ___ = Units used per month													

Energy Cost Savings Worksheet (concluded)

Energy Producible per Month	J	F	M	A	M	J	J	A	S	O	N	D	YR
14. × Btu content per unit (140,000 Btu/gal for #2 oil) ______ = Btu consumed per month													
15. Sum of lines 8, 11, and 14 = Total Btu consumed per month	64.050	70 089	64.050	57.828	52.253	45 567	37.972	30.378	36.417	42.547	48.585	57.828	
16. Gross Btu producible per month (copy line 4)	158.400	158 400	158 400	158.400	142 560	142 560	126 720	126 720	126 760	142.560	158 400	158.400	
17. ÷ 17,000 Btu per kWh (assuming a 20% conversion efficiency) = net kWh producible per month	9317	9317	9317	9317	8385	8385	7453	7453	7453	6000	6800	7200	
Electricity Consumption per Month													
18. Cost per Month	360	360	340	320	300	280	260	260	280	300	340	360	
19. ÷ cost per kWh 0.05 = kWh consumed per month	7200	7200	6800	6400	6000	5600	5200	5200	5600	6000	6800	7200	
20. Summary of savings available (must calculate)	420	460	380	380	350	300	250	200	240	280	320	380	4000

*In million Btu

Notes:

1. If direct burning of biogas for heating is anticipated, complete lines 1-15.

2. Compare lines 5 and 15. If the entry for line 5 exceeds the entry for line 15 for any month, the potential first year savings for that month is the sum of lines 6, 9, and 12. If the entry for line 15 exceeds the entry for line 5, compare the entry for line 5 successively with the entries for lines 8, 11, and 14 to determine the extent of partial replacement of existing fuels potentially available. Potential first year savings are proportional to fuel displacement levels.

3. If electricity production only is contemplated, complete lines 1-5 and 16-19. The projected first year savings are proportional to the fraction of line 19 entries represented by line 17 entries, up to the present costs shown in line 18.

4. Usage rates may vary widely over a month's period. If fluctuations exceed capacity of gas storage, actual monthly savings will be limited by the ability to match production and usage rates.

Appendix E

Energy Requirements, Farm and Home

Energy conservation begins with thorough knowledge of energy use. The following tables, based on the most reliable data available, show common farm and home energy requirements. Keep in mind, however, that energy needs vary from farm to farm.

Table 1 contains estimates for the average quantity of gasoline or diesel fuel required for most field operations used to produce corn, soybeans and forage. The figures include only the fuel required for actual field work; no allowance is included for machine preparation or travel to and from the field. Because fuel consumption for each specific operation varies among tractors, soil types and other factors, actual fuel requirements may fluctuate as much as 35 percent from the values listed in the table.

Values for tillage machines are calculated for loam soils. If your soil is heavier, fuel values should be increased slightly. Values are computed for 7-inch plowing depth and 4- to 5-inch operating depth for other tillage machines. Field speeds are assumed to be 4 to 5 mph for all tillage operations, 5 mph for planting and spraying, 4 to 5 mph for forage harvesting machines and 2.5 mph for corn and soybean harvesting. Values for row crop operations are calculated for 30-inch rows and should be adjusted for other row widths. All values are estimated by assuming efficient materials handling in the field, proper tractor weighting to keep wheel slippage below 15 percent, properly tuned and adjusted tractor engines, and efficient part-load tractor operation.

[1]Reprinted with permission from *Farming with Amoco,* 1977, No. 6, a publication of Amoco Oil Company, Chicago, IL.

Table 1. Energy Requirements - Field Operations (gallons per acre)

Field Operations	Fuel Type	
	Gasoline	Diesel
Tillage		
Shredding cornstalks	0.90	0.60
Moldboard plow	2.70	1.90
Chisel plow	1.70	1.20
Offset disk	1.35	0.95
Powered rotary tiller	2.30	1.60
Tandem disk, plowed field	0.95	0.65
Tandem disk, tilled field	0.80	0.55
Tandem disk, cornstalks	0.65	0.45
Field cultivate, plowed field	1.15	0.80
Field cultivate, tilled field	1.05	0.75
Spring-tooth harrow, plowed field	0.70	0.50
Spring-tooth harrow, tilled field	0.65	0.45
Peg-tooth harrow, tilled field	0.25	0.15
Planting (30-inch rows)		
Planter only, tilled seedbed	0.45	0.30
Planter w/fert. and pesticide attach., tilled seedbed	0.70	0.50
Till-planter (sweep)	0.60	0.40
No-till planter (fluted coulter)	0.50	0.35
Harrow-plant combination	1.15	0.80
Rotary strip-till-plant	1.50	1.05
Grain drill	0.50	0.35
Fertilization		
Anhydrous ammonia (30-inch spacing)	0.75	0.55
Weed Control (30-inch rows)		
Sprayer, trailer type	0.10	0.07
Rotary hoe	0.25	0.15
Sweep cultivator	0.65	0.45
Rolling cultivator	0.60	0.40
Sweep cultivator, w/disk hillers	0.70	0.50
Powered rotary cultivator	1.00	0.70
Harvesting		
Cutterbar mower	0.55	0.35
Hay conditioner, trailed	0.55	0.35
Mower-conditioner, PTO	0.85	0.60
SP windrower	0.90	0.60
Rake	0.35	0.25
Baler	0.65	0.45
Stack-forming wagon	0.70	0.50
Forage harvester		
Green forage	1.35	0.95
Haylage	1.80	1.25
Corn silage	5.20	3.60
High moisture ground ear corn	2.75	1.90
Forage blower		
Green forage	0.50	0.35
Haylage	0.35	0.25
Corn silage	2.00	1.40
High-moisture ground ear corn	0.65	0.45
Combine, soybeans	1.70	1.10
Combine, corn	2.35	1.60
Green forage	0.55	0.35
Haylage	0.30	0.20
Corn silage	2.00	1.40
Corn grain	0.30	0.20
Soybeans	0.12	0.08

Table 1. Energy Requirements · Field Operations (concluded)

Field Operations	Fuel Type	
	Gasoline	Diesel
Hauling, add following values to those above for each additional mile on gravel		
Green forage	0.20	0.14
Haylage	0.30	0.20
Corn silage	1.30	0.90
Corn grain	0.20	0.15
Soybeans	0.07	0.05

Source: Iowa State University

Table 2. Energy Requirements—Livestock Production

	Animal Feeding Period	Gallons per animal or 100 birds		
		Gasoline	Diesel fuel	LP gas
Swine	Raise 1 pig to market including feeding of sow and boar	0.40	0.30	0.50
Dairy	Cow milking 9,000 lb milk/yr	1.00	0.75	1.20
	Cow milking 12,000 lb milk/yr	1.35	1.00	1.60
	Heifer—1 year	0.40	0.30	0.50
Beef	Steers—grown from 400 to 1,200 lb	1.80	1.30	2.15
	Heavy steers—grown from 700 to 1,200 lb	1.00	0.75	1.20
	Heifers—grown from 400 to 850 lb	1.35	1.00	1.60
	Yearlings—grown from 650 to 1,200 lb	1.75	1.25	2.10
	Cows—winter and raise calf to 400 lb	0.90	0.65	1.10
Sheep	Lambs—native, from birth to market	0.60	0.45	0.70
	Feeder lambs—50 lb to market	0.125	0.10	0.15
Poultry	Raise 100 broilers from birth to market	0.75	0.55	0.90
	Raise 100 pullets from birth to laying	2.70	1.95	3.25
	Layers from 1 year—100 birds	7.50	5.40	9.00
	Raise 100 turkeys from birth to market	7.50	5.40	9.00

(Includes all fuel used to remove feed from storage, process, and deliver to feeders)

Source: Iowa State University

Table 3. Energy Requirements—Manure Removal

	Gallons of fuel used per animal produced		
	Gasoline	Diesel fuel	LP gas
Cleaning beef feedlots with bedding used in housing—Per animal marketed	2.25	1.60	2.70
Cleaning beef feedlots, no bedding used in housing; for feedlots holding up to 1,000 cattle at one time—Per animal marketed	1.25	0.90	1.50
Cleaning beef feedlots without housing, 1,000 to 4,999 cattle on feed at one time—Per animal marketed	0.50	0.35	0.60
Cleaning beef feedlots, without housing, over 5,000 cattle on feed at one time—Per animal marketed	0.40	0.30	0.50
Cleaning diary lots with bedding used in housing (includes scraping lots) per year—For each milk cow in herd	6.75	4.85	8.10
Cleaning dairy buildings with liquid manure collection, storage and hauling—For each milk cow in herd	9.00	6.50	10.80
Cleaning swine confinement finishing barns with liquid manure system, haul and spread—Per pig raised to market	0.40	0.30	0.50
Cleaning swine finishing barns and lots; may be added—Per pig raised to market	0.30	0.22	0.35
Cleaning sow housing, per year (includes cleaning farrowing house)	2.60	1.90	3.10

Source: Iowa State University

Table 4. Energy Requirements—Other Farm Operations

Equipment	Capacity hp or W	Estimated kWh
Barn cleaner	2-5 hp	25-40 per mo
Brooder (hogs)	250 W	1 per 4 h
Electric fence	7-10 W	7 per mo
Feed grinder (grinder blender)	2-7 1/2 hp	3-7 per ton
Feed mixer	1-7 1/2 hp	1 per ton
Grain drier (heated air)	5-40 hp	15-40 per 100 bu
Grain drier (natural air or supplemental heat)	3-7 1/2 hp	50-150 per 100 bu
Grain elevator (auger)	1/2-7 1/2 hp	4-5 per 1,000 bu
Grain elevator (bucket)	1/2-7 1/2 hp	2-3 per 1,000 bu
Hay curer, heated air	5-10 hp	10-15 per ton
Hay curer, natural air	5-10 hp	40-60 per ton
Milk cooler	1/2-5 hp	1 per 100 lb. milk
Milkhouse space heater	1,000-3,000 W	800 per yr
Milkers, portable or pipeline	1-3 hp	3-6 per cow per mo
Silage conveyer	1-3 hp	1-4 per ton
Silo unloader	5-7 1/2 hp	4-8 per ton
Stock tank heater	250-1,500 W	90-500 per mo
Ventilator (dairy and beef)	1/6-1/2 hp	1/4-1 per day per 1,000 lb animal weight
Ventilator (hogs)	1/8-1/3 hp	1/3-1 per day per 1,000 lb animal weight
Ventilator (milkhouse)	100-200 W	10-25 per mo
Water heater (milkhouse)	1,000-5,000 W	1 per 4 gal
Yard light	100-500 W	10-50 per mo
Yard light (automatic)	175-450 W	60-150 per mo

Source: University of Minnesota

Table 5. Energy Requirements—Home Electrical Equipment[1]

Appliance	Approximate wattage	Average kWh/mo
Air conditioning (central)	2-5 tons	2,000-5,000 per season
Air conditioning (window)	½-2½ tons	800-2,500 per season
Baby bottle warmer	100-500	1-4
Blanket, electric	100-200	25-50
Blender, food	200-300	1
Bottle sterilizer	500	15
Broiler	1,300-1,600	15
Can opener	175	1
Casserole	1,500	20
Cleaner, air electronic	40	10-25
Cleaner, vacuum	400-1,200	5-10
Clock	3-10	2-8
Clothes drier (electric element)	4,500-6,000	75-100
Clothes drier (gas heated, electric control)	200	4-8
Coffeemaker	600-1,000	3-10
Coffee percolator	300-600	3-10
Cooling, attic fan	¼-¾ hp	60-90
Corn popper	450-1,300	1
Deep fat fryer	1,000-1,500	10-15
Dehumidifier	300-650	100
Dishwasher (with electric heating element)	1,000-1,600	30-45
Dishwasher (without heating element)	250	10
Electronic oven	3,000-7,000	100
Fan, portable	35-210	4-10
Floor polisher	200-400	1
Floor washer	425	1
Food blender	200-300	½
Food grinder	500	2
Freezer, food (5-30 ft^3)	300-800	75-250
Freezer, ice cream	50-300	½
Frypan, electric	1,000-1,500	5-10
Furnace, gas (electric control)	25	12-25
Furnace, oil (electric control)	300	40-80
Furnace, blower	300-600	200-450
Garbage disposal	400	1-2
Griddle, automatic	1,000-1,500	10
Grill	650-1,200	5
Hair drier	200-1,200	½-6
Heat lamp	125-250	2
Heater, portable	600-2,000	15-30
Heating pad	50-150	1
Hot plate	500-1,650	10-30
House heating	10 per ft^2 floor area heated	12-15 per season per ft^2 floor area heated
Humidifier, furnace	10-200	2-30
Humidifier, portable	150-300	25-50
Incinerator	600	10
Iron, hand (steam or dry)	1,000-1,500	12
Knife, electric carving	100	6
Knife sharpener	125	¼
Lighting, home	7½-300 (bulb size)	250-800
Mangle	1,000-1,500	8-15
Mixer, food	100-350	1
Pasteurizer, ½ gal	1,500	10-40
Projector, movie	300-1,000	3-10
Projector, slide	250-750	3-8
Radio console	100-350	5-15
Radio, table	40-100	5-10
Range	8,500-16,000	100-150
Record player, hi-fi stereo	75-100	1-5
Refrigerator, conventional	250-500	5-100
Refrigerator, freezer combination	300-750	100-150
Roaster	1,000-1,600	10-40
Sandwich grill	650-1,200	6-12
Sewing machine	75-100	1-2
Shaver	12	1/10
Skillet	1,000-1,350	5-20
Sunlamp	250-500	3
Television, black and white	100-450	10-120
Television, color	500-600	45-150
Toaster, two-slice	1,000-1,200	4-6
Toaster, four-slice	1,600-1,800	8-10
Vaporizer	400-850	4
Waffle iron	550-1,300	1-2
Washer, automatic	300-700	3-8
Washer, conventional	100-400	2-4
Water heater	1,200-5,000	200-400
Water pump (deep)	⅓-1 hp	10-60
Water pump (shallow)	¼	5-20

[1]The figures represent average consumption for a family of four or five under normal conditions.

Source: University of Minnesota

Appendix F

Metric Conversions

Metric Conversion Table

To Convert	To	Multiply By
Length		
in.	cm	2.54
ft	m	0.305
miles	km	1.61
Volume		
ft^3	m^3	0.028
bushels	m^3	0.035
gal	litres (10^{-3} m^3)	3.785
Pressure		
psi	Pa (N/m^2)	6.895
Mass		
lb_f	kg	0.454
Temperature		
°F	°C	5/9 (°F-32)
Energy		
Btu	joules(J)	1055
Btu	kWh	2.931×10^{-4}
Btu	calories	252
Power		
horsepower (hp)	kW	0.746

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